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Bulletin 25

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

MINING CONDITIONS
UNDER THE
CITY OF SCRANTON, PA.

REPORT AND MAPS

BY

WILLIAM GRIFFITH AND ELI T. CONNER

WITH A PREFACE BY JOSEPH A. HOLMES AND A CHAPTER
BY N. H. DARTON

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PREFACE.

By Joseph A. Holmes.

The perpetuation of the supply of anthracite coal in Pennsylvania is a national as well as a State problem. Any investigation that shows how larger percentages of this coal may be saved in mining, without excessive cost, and without dangerous subsidence of the overlying surface ground, has a national as well as a local interest.

Messrs. Conner and Griffith, who conducted the investigations described in this report largely for the city of Scranton, are consulting engineers for the Bureau of Mines for investigations similar to those they have already made in connection with their Scranton work; and this report is published by the bureau in response to numerous requests, because of the fact that the information it contains will prove useful in the general solution of similar problems in many of the country's coal fields.

A study of the accompanying maps will show that the city of Scranton is underlain by 11 separate beds of coal, varying in thickness from 2 to 24 feet. It is estimated that before mining operations were begun these beds of coal contained underneath the present city limits of Scranton 600,000,000 tons of coal. The 27 collieries operating within the city limits, working independently of each other, had excavated and removed, up to March, 1911, an aggregate of 198,000,000 cubic yards of coal and accompanying rock, or 3,000,000 cubic yards more than the total amount of material excavated and to be excavated by the United States in constructing the Panama Canal. This fact illustrates something of the magnitude of the problem that the city of Scranton, with the aid of these engineers and of a special commission or advisory board, has undertaken to solve. The excavation has included 177,000,000 tons of coal and 44,000,000 tons of rock and accompanying refuse. This leaves about 420,000,000 tons of coal still to be removed.

As a result of other investigations and of experience in adjacent anthracite mines, Messrs. Conner and Griffith and the advisory board of engineers have advised that, as far as may be necessary to prevent dangerous surface subsidence, the spaces remaining beneath the city of Scranton from the excavation of the above-described material should be filled with sand and other materials by flushing or other processes. This operation is expensive, but it is believed to be not beyond the reach of what is practicable, nor in excess of the value of the coal that may be removed and the amount of damages that may result from the caving in of the surface if such a plan is not carried out.

No one realizes so fully as do the authors of this report the need of additional tests and other investigations before the data now presented by them can be fully accepted as sufficient for all purposes in the solution of the problem; and it is expected that at some early date a more extensive series of similar tests can be made by the Bureau of Mines under the supervision of Messrs. Conner and Griffith on a larger scale and under a greater variety of conditions.

The field examinations made for the Bureau of Mines by N. H. Darton, which are described briefly in a chapter of this bulletin and will be discussed at length in a bulletin to be published later, indicate the extent and distribution of the sands, gravels, and other materials in the Scranton-Wilkes-Barre district available for flushing purposes if further tests indicate their relative merits; and it is expected that the relative merits of these different materials will soon be tested under such conditions as will furnish the desired information.

MINING CONDITIONS UNDER THE CITY OF SCRANTON, PA.

By WILLIAM GRIFFITH AND ELI T. CONNER.

LETTER OF TRANSMITTAL.

To the honorable Mayor and Council of the City of Scranton, and to the Board of Control of the Scranton School District:

GENTLEMEN: In rendering to you the following report upon the mining conditions under the city of Scranton, with observations and recommendations for the amelioration of the same, we feel that an apology is due for the voluminous proportions of the document. We trust, however, that you will consider the magnitude of the subject, and the manifest necessity under the circumstances of sacrificing brevity for clearness.

We have considered all the phases of the question in hand as fully and thoroughly as possible, having not only exhausted all the sources of present information available to us, but having made many tests and experiments as to the strength of materials and the efficiency of roof-supporting devices, both those at present in use and those originated by us. We may, therefore, perhaps be pardoned for felicitating ourselves with the consciousness that the whole question has been investigated and is herein considered with all the completeness which our ability and limitations would permit.

We desire to express our appreciation of the pleasant and courteous manner in which all the mining companies, including managers, superintendents, and inside officials, and the officials of the Fritz engineering laboratory of Lehigh University, have assisted us during the progress of the investigation, for without this cordial cooperation this report could not have been submitted in its present completeness. Our acknowledgments are also due to and on account of the treatment accorded us by the officials of the city and board of control, by the press and the public, and to Mr. S. N. Callender, for the use of his copy of the city atlas. Also to the members of the advisory board, for the care and enthusiasm with which they have considered this report, and for their practical suggestions, which are incorporated herein.

Very respectfully,

WM. GRIFFITH,
ELI T. CONNER.

SCRANTON, PA., *March 20, 1911.*

SUMMARY.

We would summarize our findings as follows:

The report is accompanied by plates which present a full set of plans of the city of Scranton and the mine workings thereunder, and also cross sections showing the positions of the several beds of coal and the intervening strata. From these plates one can readily determine, at almost any given point, the depth of the coal below the surface, the thickness of the beds, and the thickness of the intervening strata, since all of the plans are drawn to scale. These plates should be carefully studied in connection with the report and tables. As provided for in our contract, these plans are based upon information obtained from the maps, records, and data loaned to us by the several mining corporations, the Pennsylvania geological survey of 1885, and from our own personal investigations and measurements.

It will be noted that the coal basin underlying the city is wide and comparatively shallow, so that the coal beds and the intervening strata are comparatively flat, by reason of which fact the artificial pillars that may be inserted are not at all liable to slip or move on account of the dip of the seams. The only part of the coal measures underlying this city where there is an excessive dip is along the West Mountain, where pitches as steep as 50° are found. There is only a small part of the surface underlain by such pitching seams that carries important improvements, namely, in the vicinity of No. 23 School and what is locally known as the "Notch."

After about 40 days of careful inspection of underground conditions at all of the collieries operating within the city limits, we find that the total quantity of coal and refuse that has been extracted under the city of Scranton is about 221,000,000 tons.

There has been produced for market from the 27 collieries, 177,000,000 tons of coal.

The space excavated under the city is about 198,000,000 cubic yards. The total estimated excavation by the United States for the Panama Canal is 195,323,000 cubic yards.

It must not be understood that the hole from which the above material has been taken is still open. It is, of course, impossible to say what percentage of the space excavated remains open, but we would express the belief that it does not exceed one-half of the original, due to the numerous squeezes and cave-ins that have occurred.

After spending more than 40 days' time studying maps, after testing various materials used and considered for roof support in the mines, and after tabulating and considering the information gained by these investigations, the conclusions we have reached are as follows:

Although some other devices are locally useful, the only method that combines the necessary qualities of strength, ease of application, and reasonable cost is filling the underground openings by what is known as the "flushing" method, using for flushing culm, sand, crushed rock, and other fine material that can be washed into the mines with water. This method was originated in the anthracite region of Pennsylvania, and has been extensively adopted in European mines, where, at great expense, sand, loam, and crushed rock are flushed into the mines following the removal of the coal by the longwall method of mining.

The tables and estimates of cost contained in the body of the report give in detail the results of our investigations and conclusions.

We therefore offer as our only recommendation that the flushing method be adopted, under the plans and specifications contained in the body of the report and in plates 1 to 24. From the report the following general conclusions are drawn:

1. Speaking broadly, the surface of the city can be supported by the methods recommended, and at a cost not in any sense prohibitory when considered with relation to the value of the property and operations for which support is absolutely essential.

2. Although in our judgment there are points in the city, as indicated in the detailed report, where at the present time there is distinct and immediate danger to life and property, yet the total area immediately threatened constitutes but about 15 per cent of the entire area of the city, and the danger is mainly from workings in surface beds.

3. On the west side the beds of the middle series are thick and close together, and the pillars are not columnized, creating a dangerous situation where the workings have not been closed by previous caves. Particular areas thus threatened can not be definitely specified on account of the inaccessibility of much of the mined-over area. Detailed investigation should be made of the portions of the mines not already closed. Relatively, we do not believe that a large part of the territory mentioned is threatened on account of so much ground having been already closed by caves.

Special attention is called to the conditions under schools Nos. 13, 23, and 29. They should be attended to promptly.

The lower series of beds, namely, the three Dunmores, are so thin and so far below the surface that with the usual system of mining we do not think they constitute a serious menace to the improvements on the surface, except along the margin of solid blocks of unmined coal and near the outcrops. In the deep-lying parts of the Dunmore beds we believe these solid blocks should be mined.

4. It would seem, therefore, to be not only the part of wisdom, but absolutely obligatory, to immediately commence supporting the points menaced, and thereupon proceed upon a general policy of giving support to the entire area of the city, for it must be borne in mind that with the mining activities that are constantly going on other and additional points of danger are not only liable to, but in all probability will, develop with each passing year—it might almost be said with each passing month.

5. Where the owner of the surface has undoubted right to the support thereof by coal pillars, in our opinion he could permit the removal of such pillars; the value thereof would under average conditions pay for such artificial support as we have recommended, if it be assumed that the pillars were mined and the support constructed by the same operating company. This observation, however, is based upon the assumption that in such case the operating company is one of the large transportation companies, inasmuch as although there might not be a profit in the immediate transaction of mining the pillars and installing the support, there would, of course, be a profit to such companies in carrying the coal to market.

6. Culm flushing should be used only in coal beds having light cover, up to 200 to 500 feet, according to the settlement expected. But sand, being four or five times as strong as culm, is better, and, being suitable for filling all beds under Scranton, is to be preferred.

7. We believe that the conclusions adduced from the tests made, and the calculations and tabulations based thereon, are reasonably reliable; yet we desire to record the opinion that there are conditions existing in the mines to which they might not apply. Such might be the case, for instance, in localities where several beds of coal are separated by thin strata of shale and slate or even sandstone, and the pillars in the two or more beds are not over one another, and it is proposed to reclaim all or any part of the pillars.

Even though an application of the above-mentioned tables might appear to fit the conditions, we believe that the only permissible procedure would be to first fill with flushed material all of the openings in the lowest bed of the series, and then fill upward until all the beds are filled, care being taken to have the flushed areas over one another. After all of the openings in all of the beds have been filled the pillars in the uppermost bed may be attacked, and the space occupied by each pillar filled as soon as the pillar is removed. No pillar reclamation should be permitted in any of the other beds until all of the pillars in the upper bed have been removed and the overburden has come to rest on the flushed material; after which the pillars in the next lower seam may be attacked and handled in like manner.

8. Harmonious plans and procedure between the coal companies, the city, the school authorities, and the public are essential to the

successful carrying out of any relief measures that are herein or may be hereafter suggested. Some facts that should be evident to all are that the prosperity of the city and of the community is to a large extent dependent upon the coal companies; that drastic laws or regulations that may curtail the mining of coal will necessarily react on the prosperity of the community; and that any ameliorating plans or compromises which it may be possible to effect between the city and the mining companies tend to prolong the life of the mining industry in Scranton and vicinity, and should be promoted.

It should therefore be the aim of all interested in mine-cave protective measures and of the companies operating the mines to adopt plans that will best conserve the welfare of all interested.

The expenditure for the work would of course be distributed over many years, the relief measures being applied at the points most in need of protection and as rapidly as proper arrangements could be effected and the necessary details, surveys, etc., prepared.

For the businesslike carrying out of the plans suggested it is recommended that a protective commission be established, consisting of not less than three nor more than five men, representing the city authorities, the school board, and the coal companies—this commission to have full and complete authority for the execution of the plans, and to be approved by the proper legal action. The commission should employ an engineer who should devote all his time to the service as active manager of the work.

THE REASON WHY.

The occasional mine caves or settlements in various parts of Scranton during the past years had long caused more or less public concern, until finally popular sentiment was brought to a focus by the settlement in Hyde Park, on August 29, 1909. This subsidence seriously damaged public school No. 16 and much other surrounding property; and, if it had occurred while school was in session, might have been the cause of loss of life.

Immediately following this event committees of councils, board of control, and board of trade took action in an endeavor to discover the immediate physical causes of the caving, as well as the legal responsibility therefor; and after much consideration, the former mayor, Hon. J. B. Dimmick, who was called in consultation with the joint committee, proposed the plan as set forth below and quoted from his final report, to wit:

To the joint committee of mine caves of select and common councils and of the board of control, Benton T. Jayne, chairman:

GENTLEMEN: I beg leave to herewith make report of what I have been able to accomplish in pursuance of your instructions looking to the selection of an engineer to be employed by the city and the board of control for the purpose of making a study of the physical aspect of the entire mine-cave problem as it affects our city, and to make a report thereon together with such recommendations as would seem fitting and practicable.

Shortly after I received your instructions I laid the entire situation before John Hays Hammond, the well-known engineer, and he at once not only became deeply interested in the problem but offered his aid and assistance without compensation, direct or indirect, being moved simply by a willingness to perform public service.

After much thought and conversation with the gentlemen whose names are hereinafter given, the following definite plan has been worked out and awaits but acceptance upon the part of the city government and the board of control.

PLAN.

An advisory board has been formed consisting of five well-known engineers, with power to add to their number, namely: John Hays Hammond, D. W. Brunton, R. A. F. Penrose, jr., Lewis B. Stillwell, and W. A. Lathrop, this board having all agreed to act without compensation.[a] After a careful investigation of the necessary qualifications of the engineers that would make the actual study upon the ground, they suggested the names of Eli. T. Conner, of Philadelphia, Pa., and William Griffith, of Scranton, Pa., Mr. Conner having had considerable experience in anthracite-mining operations, and Mr. Griffith being especially informed as to the geological formation of this section. These two engineers to be employed by the city and the board of control, and upon the filing of their report, the same to be carefully considered and passed upon by the advisory board.

In order that the matter might be in complete form for your consideration, I secured from the two engineers, as recommended, a definite proposition, which is herewith incorporated in extenso:

SCRANTON, PA., *May 25, 1910.*

Hon. J. BENJ. DIMMICK, *Scranton, Pa.:*

As a result of our conference with you yesterday, in accordance with your request made at that time, we respectfully submit the following:

Of course, it is recognized by everybody that the situation is serious regarding the mining conditions under portions of the city of Scranton, and the proposition of proecting the whole city can best be met by a frank recognition of the varying conditions that undoubtedly exist, certain sections of the city being really in danger, while others are, practically speaking, not menaced. While our proposed report would be general in character, and intended to cover the entire city, yet it would properly be especially concerned with those sections of the city that are immediately threatened.

It seems to us that what is most necessary at the present time is more accurate knowledge of the physical conditions which now prevail, and we would suggest a report based upon the results of a careful study of such physical conditions as they at present exist in the mines under the city of Scranton; this report to be general in its nature. We would group together the various similar conditions in several classes, to each of which similar remedies or lack of remedy might apply, with suggestions not only as to remedies but also as to the approximate cost thereof under certain ascertained conditions. We should expect to also include in said report such general observations and recommendations touching the entire situation as would seem to be justified by our inspection and study thereof. The completeness and value of any such report would depend in a large measure upon the assistance and cooperation tendered us by the several mining companies who are now operating under the city and of the city and school authorities.

---

[a] The advisory board subsequently included the following additional members: Dr. H. S. Drinker, president of Lehigh University; Dr. J. A. Holmes, director of the Bureau of Mines; Prof. J. F. Kemp, Columbia University; Prof. J. F. McClelland, Yale University; and Prof. H. L. Smyth, Harvard University.

It is to be distinctly understood that such proposed report and study of the situation existing under Scranton would be based upon such information as might be obtained from the second geological survey and from such other maps of the various coal-mining companies and the city and school authorities, to which access could be obtained for the engineers, and from such personal inspection of accessible portions of the mines as, in our judgment, shall be necessary. We would, however, give expression to our belief that such surveys are sufficiently accurate and reliable as a basis for the general conclusions that the report will be expected to set forth.

It seems to us that the information to be secured through such a report would be the first requisite to a subsequent detailed investigation and application of any remedies which might be suggested for the amelioration of the mining conditions under this city.

Yours, respectfully,

(Signed) WM. GRIFFITH,
ELI. T. CONNER,
Mining Engineers.

It therefore remains but for the community, through its city government and the board of control, to employ these two engineers at the price stipulated in order to receive a general report upon the cave problem that should command the respect and the confidence of all parties interested, not only because it will have been prepared by engineers selected by a board composed of experts of national reputation, but also because the very findings of such engineers would, in their turn, be submitted to and reported upon by that same advisory board. In short, the community would then be provided with information as to facts and opinions as to remedies that would form solid ground for both future deliberations and future activities.

I can not refrain from suggesting, assuming the acceptance of this most unselfish offer upon the part of men of high professional equipment and without personal interest in the welfare of Scranton, that, simultaneously with the enactment of the necessary legislation to carry into effect this plan, there should be official appreciation of their proffered assistance.

Respectfully submitted.

J. BENJ. DIMMICK.

Certified copy.
EVAN R. MORRIS, *City Clerk.*
SEPTEMBER 15, 1910.

GEOLOGY.

The city of Scranton occupies the surface overlying the whole width (5 miles) of the Lackawanna coal field, and extends about 5 miles up and down the valley. The central part of the city is over the center of the coal basin, while the margin of the basin on the East and West Mountains nearly coincides with the city line along those hills.

The floor of this coal basin is formed by the hard Pottsville conglomerate or "pudding stone," which comes to the surface on the mountain sides east of Roaring Brook, and dipping down under the surface in the form of a deep trough or basin passes under the central part of the city at a depth of several hundred feet, and again reaches the surface on the flanks of the West Mountain. Passengers on the Laurel Line can note this conglomerate on both sides of the Roaring Brook ravine and at the stone quarry on the east near the switch where the Dunmore branch leaves the main line.

It is the conglomerate that forms the roof of the Lackawanna tunnel at Nay Aug, and is again cut by this railroad on the west side of the valley, at Leggetts Creek Gap.

As before stated, this rock forms the floor of the coal basin. No coal exists below it; therefore all the coal under the city of Scranton is to be found in the rocks which fill this trough or basin and overlie the Pottsville conglomerate. The coal is deposited in parallel layers or beds, known locally as "coal veins," that are approximately parallel to the conglomerate floor, and lie deepest in the central part of the basin. They extend with persistence and considerable regularity from outcrop to outcrop, except where they were removed with other rocks during the surface erosion of past ages.

In all, there are 11 principal coal beds under this city, known by names as follows, beginning with the highest:

The Eight-Foot coal bed, which is present only in two small areas or islands under the highest part of the Hyde Park hill.

The Five-Foot and Four-Foot beds, which are only in the hill top on the west side from Dodge to Marvine, above the level of the Lackawanna River.

The Diamond and Rock beds, which are on the west side only of Lackawanna River, under Bellevue, Hyde Park, Providence, and parts of Keyser Valley.

The Big or Fourteen-Foot and New County beds, which extend under the whole west side, and also become surface beds on the east side at the National colliery, near the south line of the city; also under the central city and hill section, nearly to the Moses Taylor Hospital.

The Clark, Dunmore No. 1, Dunmore No. 2, and Dunmore No. 3 beds, which extend under the whole city from Nay Aug Park to the West Mountain.

For the thicknesses of these several beds, the distances between them, and their relative positions in the coal measures, the reader is referred to the columnar section sheets contained in Plates 1 to 24 of this report.

HISTORY.

EARLY DEVELOPMENTS.

The late Dr. B. H. Throop reported to an industrial convention at Tunkhannock, in the year 1842, that the Lackawanna Valley from Archbald to Pittston "contains upward of one hundred coal mines opened, and many of them are made at present a source of profit both from domestic and foreign markets. There are sent some five or six thousand tons of coal annually by sledges and wagons to the States of New York and New Jersey, in exchange for salt, plaster, etc."

In 1841 the first furnace of the Lackawanna Iron & Coal Co. was filled and fired, and though this effort to manufacture iron from local ores proved a total failure, it nevertheless gave a decided impetus to the coal-mining industry of this locality. Subsequently iron ore and limestone were brought from a distance, and anthracite was successfully used for smelting iron. Since this beginning the coal industry of Scranton has continuously flourished until the present.

The mines worked by the iron company in 1841 were on both sides of Roaring Brook. The Clark bed was worked near the viaduct; later the Dunmore beds were worked near the site of the present Laurel Line power house by what were known as the Rolling Mill drifts. For several years these were the principal mines in Scranton.

In 1851 the Lackawanna & Western Railroad was built from Scranton to connect with the Erie road at Great Bend. The Delaware & Cobbs Gap road (chartered in 1849) was merged with the Lackawanna, and in 1856, under the name of the Delaware, Lackawanna & Western Railroad, was built through from Scranton to the Delaware River. In 1858 the Lackawanna & Bloomsburg road was built. Equipped thus with new and permanent outlets for its resources, the mining industry of the valley and the city advanced with rapid strides.

About 1852 the Diamond mines were opened. In 1854 the Rockwell mine at Leggetts Gap, and the Bellevue colliery were opened. The opening of numerous other coal operations followed in rapid succession.

MINING METHODS.

The room and pillar system of mining was adopted in these old mines, and has been continued in all the mining of the region to the present time. This method consists, briefly, in driving an airway and a gangway about 15 feet apart and parallel in the coal bed. On the high side—that is, to the rise—chambers or rooms are driven parallel to each other and at right angles to the gangways. The rooms are about 30 feet wide and are separated by partitions about 15 feet in thickness called pillars. The coal production of the mine is mainly taken from the contents of the rooms; the pillars, which comprise approximately one-third of the coal, are left to support the surface. This practice of leaving one-third of the coal for surface support was adopted at the start, and was found sufficient for the comparatively light overburden to be sustained in the mining of the beds near the surface. It has been continued as an empirical rule with little variation, in the deeper mining under the city, without reference to the weight on the pillars or the strength of the coal.

In the past the several beds of each mine were worked independently of each other and no attempt was made to regulate the size, position, and distribution of pillars aside from the one-third rule. Consequently, the pillars are not columnized; in other words, they are not exactly over each other. Many of the thick beds of the middle measures under the Hyde Park and Providence sections are close together. Therefore the pillars in these thick beds, not being columnized, have a decided tendency to crush through the interval between the beds, the pillars of an upper bed settling into the excavations or rooms of the lower workings.

Another feature that should be brought out in this historical sketch of early mining in Scranton is that the universal practice in the old days was to mine only the best, thickest, and most accessible coal beds, and also only the profitable parts of each bed, and to leave unmined, as refuse, the parts which for one cause or another were found more expensive to work. Therefore, in these latter days some of the coal beds already mined over and ready to be abandoned have been found to carry rider coal above or bottom coal below, which can be removed at a profit. And, therefore, for the past few years the total production from several beds has been from such remining of top and bottom coal. This remining, of course, leaves the pillars from 2 to 6 feet taller than they were before for the same horizontal area, consequently the pillars are much weaker and less able to support the overburden.

In consequence of the several conditions related above there have been from time to time numerous and more or less serious caves or subsidences of the surface, principally on the west side, which have caused some damage to surface property, but no loss of life. In every instance the damage has been speedily repaired and temporarily forgotten. The accumulated result of these repeated subsidences has probably left certain parts of the surface in that section of the city in more stable condition than they were before. This phase of the subject, however, will be considered in a subsequent chapter.

STATISTICS OF COAL PRODUCTION.

The following statistics of the coal-mining industry in Scranton are based upon the result of the surface and underground investigations made by us, and from our inspection of the mine maps, taken in conjunction with the annual production of coal as shown in the published statistics contained in the reports of the State mine inspectors.

TABLE 1.—*Total production of coal mined under the city of Scranton, 1841–1910.*

Year.	Production.
	Long tons.
1841–1872	22,760,000
1872	2,155,647
1873	2,570,081
1874	1,630,158
1875	2,312,580
1876	1,572,033
1877	1,818,867
1878	1,732,782
1879	2,670,629
1880	2,477,285
1881	3,002,761
1882	2,996,795
1883	3,280,001
1884	3,038,291
1885	3,261,483
1886	3,092,069
1887	4,054,109
1888	4,474,419
1889	3,724,127
1890	4,032,073
1891	3,795,911
1892	3,921,894
1893	3,992,640
1894	3,614,488
1895	4,042,677
1896	3,882,848
1897	3,935,907
1898	3,527,826
1899	4,308,338
1900	4,381,573
1901	6,041,215
1902	4,345,310
1903	6,578,771
1904	6,202,694
1905	6,257,380
1906	6,163,199
1907	6,948,258
1908	6,336,726
1909	5,915,774
1910	6,000,000
	176,839,619

TABLE 2.—*Statistical table of coal mining.*

Coal beds.	Average thickness of beds.	Original area before mining.	Area mined over.	Area to be mined.	Approximate area of pillars.	Area of mine excavation.	Foot-acres mined over, including pillars.	Foot-acres excavated, excluding pillars.	Foot-acres to be excavated, leaving one-third for pillars.
	Feet.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*			
Eight-foot	7.6	140	111	29	35	76	843	577	146
Five-foot	4.4	2,000	1,093	907	364	729	4,809	3,208	2,660
Four-foot	3.6	2,460	994	1,466	331	663	3,578	2,387	3,518
Diamond	9.4	4,160	3,562	598	1,187	2,375	33,495	22,325	3,746
Rock	5.2	4,500	3,000	1,500	1,000	2,000	15,600	10,400	5,200
Big	12.2	6,000	4,831	1,169	1,610	3,231	58,938	39,296	9,508
New County	6.0	5,360	1,549	3,811	516	1,033	9,294	6,198	15,244
Clark	6.7	7,860	6,040	1,820	2,013	4,027	40,468	26,981	8,130
Dunmore No. 1	3.0	7,500	690	6,810	230	460	2,070	1,380	13,620
Dunmore No. 2	4.0	9,630	2,533	7,097	844	1,689	10,132	6,756	14,194
Dunmore No. 3	3.3	8,500	1,573	6,927	524	1,049	5,191	3,462	15,240
	....	58,110	25,976	32,134	8,654	17,322	184,418	122,970	91,206

Total space excavated in the mines under Scranton	cubic yards	198,104,670
Total estimated excavation for Panama Canal	do	174,666,594
Total approximate tonnage of coal produced to January 1, 1911	long tons	176,840,000
Total approximate tonnage of coal waste and mine refuse excavated, but not included in production	long tons	44,500,000
Average production per foot-acre excavated	do	1,440
Average production per foot-acre mined over	do	960
Number of collieries and mines operating under the city		27

PRESENT MINING CONDITIONS UNDER SCRANTON.

The following tabulated notes give in condensed form the actual conditions of the mining under the city and school properties at present, as found by your engineers during an extended underground inspection that lasted about 40 days.

In connection with these notes the plates accompanying this report should be well studied. These plates set forth in a more intelligible form than can possibly be shown by words the location and extent of the mining in all the coal beds under the city, and by plans, cross sections, columnar sections, etc., clearly indicate the geology and distribution of the beds throughout the measures.

Scranton Coal Co. collieries.

PINE BROOK COLLIERY.

(Works central city section from the river to Nay Aug and from Poplar Street to Beech Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		do	Do.
Four-foot		do	Do.
Diamond		do	Do.
Rock		do	Do.
Big	Technical High	Inaccessible, but reported flushed. (See Stevenson and Knight report.)	53 acres mined over. Depth, 30 to 50 feet (see sections on Pls. 2, 3, 4, and 5); thickness, 12 to 16 feet; pillars sound where observed; local falls; old workings mainly fallen and inaccessible.
	No. 33	Near outcrop; probably unminable or absent.	
	Central High	Partly mined and partly inaccessible; pillars sound; 8 iron posts and gob stoppings, behind which inaccessible; reported filled. (See Stevenson and Knight report.)	
New County		Not mined	Not mined; 3 feet thick.
Clark	No. 4	Pillars sound, as shown on maps; not much chipping; no evidence of disturbance.	584 acres mined over. Thickness, 7 to 12 feet, including 2 to 4 feet of impurities; depth, 150 to 200 feet. (See sections on Pls. 2, 3, 4, and 5). Character friable; pillars subject to chipping. Old workings between Gibson and and Ash Streets and from Capouse to Quincy Avenue show weakness due to weight, and indicate incipient squeeze. Old Iron Co. workings both sides Roaring Brook. North side bounded by Madison, Vine, and Clay Streets and the brook. South workings side lying between the brook and Pittston Avenue are inaccessible. The bed is near surface and thick, and old maps show very small pillar support.
	No. 9	Pillars sound and no disturbance.	
	No. 33	Pillars sound and undisturbed; chambers filled with dry ashes.	
	Technical High	Chambers large; all pillars small and weak; roof fallen in all chambers.	
	Central High	Pillars, as shown by maps, relatively small, and apparent weakness shown by chipping; gob piers built; flush pipe passes under and beyond school.	
	No. 36	Filled with water and inaccessible.	
Dunmore No. 1	No. 4	Chambers nearly filled with rock; pillars strong; conditions good.	349 acres mined over. Bed 4 to 5 feet thick; some places increased by top bench; bottom taken up for height; chambers partly filled with rock; general conditions good; depth, 200 to 270 feet (see sections on Pls. 1, 2, 3, 4, and 5).
	No. 9	Inaccessible on account of water; reported partly full of rock.	
	Technical High	Chambers nearly full of rock; pillars sound; conditions good.	
	Central High	Pillars large; only partly mined; conditions good.	
	No. 33	Chambers nearly filled; conditions good.	
	Nos. 35 and 36	Not mined.	

Scranton Coal Co. collieries—Continued.

PINE BROOK COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 2	No. 4	Pillars sound; chambers three-fourths filled with gob rock; no disturbance.	852 acres mined. Bed 3 to 5 feet thick; 1 to 2 feet of bottom raised for height; chambers nearly filled with gob, except road in center; pillars strong and conditions generally good, except old Rolling Mill drift and slope both sides of Roaring Brook, where pillars are small and openings large. (See sections on Pls. 1, 2, 3, 4, 5, 18, 22, and 24.)
	No. 36	Pillars sound and large.	
	No. 9	Inaccessible on account of water. (See Stevenson and Knight report.)	
	No. 35	Pillars sound; conditions good. Now working.	
	Technical High	Roof falls prevented access; reported good; pillars and chambers partly filled.	
	No. 33	Pillars sound; chambers nearly filled; conditions good.	
	Central High	Partly mined only; Sanderson reservation to southward not yet mined.	
	No. 3	Now mining 5 feet 7 inches; raising 2 feet of bottom rock; coal pillars firm; chambers one-half filled with gob; conditions good.	
	No. 2	Old workings; recently unwatered; pillars small; rooms large; local falls; all quiet.	
Dunmore No. 3	No. 36	Pillars slightly chipped; otherwise strong, and as per map; three-fourths of space outside of roadway filled with gob; conditions good.	354 acres mined. Bed 2½ to 5 feet thick, including 10 to 18 inches refuse; all chambers nearly filled with gob, except roadway in center; pillars strong and conditions generally good; depth, 300 to 350 feet (see sections on Pls. 1 to 24).
	Central High	Not now mined, but being extended; near-by workings three-fourths filled with gob; conditions good.	
	No. 33	Coal vein is faulty; thin and impure coal now worked; 3 feet top rock being taken down and workings being filled tight; conditions good.	
	Technical High	Inaccessible on account of water in adjacent workings; three-fourths filled with gob, except roads; conditions good.	
	No. 9	Pillars sound; chambers three-fourths filled outside of road; conditions good.	
	No. 4	Pillars strong; chambers filled, except road; conditions good.	

MOUNT PLEASANT COLLIERY.

(Works Hyde Park, from Lackawanna River to Keyser Creek, and between Lafayette and Pettibone Streets.)

Eight-foot	No. 18	School over outcrop of bed; bed not mined	33 acres mined. Depth, none at outcrop to 80 feet over center of area (see Pls. 14, 16, and 17); thickness, 8 feet 8 inches in center; 1 foot 5 inches refuse; all mined over, except stripping at outcrop, and abandoned; pillars standing in good condition.
Five-foot	do	Depth, 134 feet; openings filled with gob and falling fire clay; pillars reported standing firm, reinforced by this falling strata shaken by old squeeze in lower beds; present conditions fair	122 acres mined. Depth, none at outcrop to 200 feet (see sections on Pls. 14, 16, and 17); thickness, 5 feet 8 inches; includes 10 inches of bone at top; bed overlaid by 3 feet 5 inches of falling fire clay; all abandoned parts filled with falling fire clay; conditions fair.
Four-foot	do	Depth, 164 feet; pillars large and firm; rooms filled with rock	120 acres mined. Depth, see sections on Plates 14, 16, and 17; twin bed; top coal, 1 foot 10 inches; dividing rock, 6 to 7 feet; bottom coal, 3 feet; pillars sound; rooms filled with rock; conditions good.
Diamond	do	Mined, closed, abandoned, and inaccessible; depth, 280 feet	188 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness about 10 feet; soft falling roof; workings formerly squeezed; [a] now closed by falling rock and inaccessible.
Rock	do	Mine abandoned and inaccessible account falls and old squeeze; depth, 315 feet.	190 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 7 to 8 feet; 1 foot 2 inches refuse; reported pillars more than 33 per cent, but mine closed and inaccessible on account of squeeze. [a]
Big	do	Depth, 376 feet; workings inaccessible on account of roof falls, but pillars reported large and not crushed. (See maps.)	214 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 14 feet 9 inches; 1 foot 7 inches refuse; workings partly open, but mainly closed by local falls and old squeeze. [a]
New County	do	Partly mined; rooms filled with rock; remaining coal soon to be mined, leaving usual pillars; depth, 418 feet.	208 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 9 feet 8 inches, includes 1 foot 10 inches of refuse; open and accessible; rooms partly filled with gob; pillars sound, usual size; conditions good. [a]
Clark	do	Substantial pillars; some chipping; no indication of settlement; depth, 481 feet.	202 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 6 feet 5 inches, includes 8 inches of refuse; rooms wide; pillars slightly air chipped, but otherwise sound; conditions fair.
Dunmore No. 1	do	Depth, 598 feet; only partly mined, by two gangways; no chambers.	32 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 1 foot 4 inches to 1 foot 8 inches; vein too thin for profitable mining and now abandoned; openings filled with gob; conditions good.

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Scranton Coal Co. collieries—Continued.

MOUNT PLEASANT COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 2	No. 18	Depth, 612 feet; large pillars, sound and undisturbed; rooms nearly full of gob.	92 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 4 feet 3 inches; rooms nearly full of gob; conditions good; at northwest end of property vein too thin to mine at present.
Dunmore No. 3	do	Pillars sound, of usual size; chambers partly filled; depth, 704 feet.	115 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 4 feet 3 inches, includes 1 inch slate and bone top; rooms nearly filled with gob; floor raised for height.

CAPOUSE COLLIERY.

(Works Keyser Valley from Keyser Creek to outcrop and from Jackson Street 1 mile northeastward.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		do	Do.
Four-foot		do	Few surface improvements.
Diamond	No. 17	Depth, 92 feet; inaccessible under school on account of removal of surrounding pillars, but under school for area of 200 feet square pillars reported sound and still standing.	262 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 10 feet; workings have been remined, and pillars removed over a large area; mining in Diamond bed has ceased.
Rock	do	Depth, 136 feet; inaccessible for reason stated above; similar conditions prevail; nearest accessible point 400 feet from school.	193 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 3 feet 10 inches; rooms two-thirds filled with gob; partly remined and inaccessible.
Big	do	Depth, 216 feet; pillars as shown on maps; sound, except slight chipping; local falls in rooms under school.	317 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 13 feet 3 inches, includes 9 inches refuse; local falls; no remining as yet; few improvements on surface.
New County	do	Depth, 246 feet; rooms two-thirds filled with gob; also local falls; pillars good; no indication of settlement.	100 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 6 feet 8 inches, includes 2 feet 11 inches of refuse; rooms two-thirds filled with gob; numerous local falls in chambers; no indication of present settlement; remining near outcrop.
Clark	do	Depth, 311 feet; water under school prevented approach nearer than 150 feet; pillars sound, except some chipping; rooms wide; pillars usual size, well distributed; conditions fair.	412 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 8 feet, includes 11 inches refuse; many local falls, but no squeeze or other settlement; good roof; fair conditions at present; no remining except at outcrop.

Dunmore No. 1	do	Depth, 360 feet; not mined	This vein not mined as yet; too thin. Depth, see sections on Plates 12, 13, and 14.
Dunmore No. 2	do	Depth, 380 feet; pillars sound, usual size; rooms nearly filled with gob; conditions good.	139 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 3 feet 2 inches, includes 6 inches refuse; bottom raised for height; no falls; rooms filled with gob, except roadway; conditions good.
Dunmore No. 3	do	Depth, 480 feet; not mined	55 acres mined. This vein not being mined; too thin for profitable mining at present.

WEST RIDGE COLLIERY.

(Works Providence section, North Main Avenue to outcrop between Putnam and Clearview Streets.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 40	Depth, 66 feet; workings inaccessible; approached to point about 300 feet from school; workings filled with falling fire-clay roof; workings now controlled by Clearview Coal Co.	84 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 4 feet clear; roof falling; 3½ to 4 feet of fire clay and bone that fall soon after mining and fill the chambers; driving chambers stowed with rock from next vein below. Much of the surface is unimproved.
Top split of Four-foot.	do	Depth, 88 feet (see Clearview Coal Co., p. 43)	9 acres mined as separate bed. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 18 to 30 inches; 3 to 4 feet of rock raised for height; all available space filled with rock and the surplus stowed in Four-foot and Five-foot beds.
Four-foot	do	Depth, 118 feet. Reported formerly worked by West Ridge, but this part now controlled by Clearview Coal Co. (see p. 43).	90 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 3 feet clear coal; falling rock roof; workings filled with falling roof and rock from top split.
Diamond, Rock, Big, New County, Clark.	do	These beds worked by Von Storch colliery and Delaware & Hudson Co. (see p. 35).	See page 35.
Dunmore No. 1	do	Depth, 564 feet; extensions of working here since Stevenson and Knight report; pillars sound and chambers well filled, except roadways.	36 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 3 feet 1 inch, 4 inches of refuse; 3 feet of bottom raised for height; rooms filled with gob, except roads; pillars sound; conditions apparently good.
Dunmore No. 2	do	Depth, 616 feet; workings now extended under this school; pillars sound and usual size; rooms filled with gob, except roadway; conditions good.	43 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 2 feet 8 inches, 3 inches of refuse; 4 feet of bottom taken up for height; rooms, except roadway in center, filled with gob.
Dunmore No. 3	do	Depth, 686 feet; mined under school, but inaccessible on account of gas and water; conditions reported unchanged since Stevenson and Knight report.	99 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 3 feet 9 inches, including 7 inches of refuse; at west end of property this bed is too thin to mine as yet; 2 to 3 feet of bottom raised for height; rooms nearly full of rock, except roadway; first mining completed and abandoned.

Scranton Coal Co. collieries—Continued.

RICHMOND NO. 3 COLLIERY—BRYDEN SHAFT.

(Works center of valley. Area bounded by river, Olyphant Road, and Manville farm and narrow strip extending to East Market Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot	No. 39	Eroded	Eroded.
Five-foot	do	do	Do.
Four-foot	do	do	Do.
Diamond	do	do	Do.
Rock	do	Depth, 138 feet; not mined	Not mined; depth, 109 feet under river flats; much sand and gravel, with thin rock cover over bed; too dangerous to mine.
Big	do	Depth, 200 feet; pillars large and firm; present conditions good	86 acres mined. Depth, see sections on Plate 9; thickness, 13 feet 1 inch; 2 feet 7 inches refuse; top bench not removed on first mining; now being mined; conditions fair; under river flat considerable depth of gravel and sand above the rock.
New County	do	Not mined	Depth, see sections on Plate 9; not mined; too thin or dirty to be profitably mined at present.
Clark	do	Depth, 366 feet; pillars usual size and sound except air chipping; roof good; no indication of settlement.	95 acres mined. Depth, see section on Plate 9; thickness, 5 feet 9 inches, including 4 inches refuse; pillars look fair, but all show chipping, probably air-slacked.
Dunmore No. 1	do	Thin and unworkable at present	Thin and not mined. At Dickson and Manville this bed is split; the upper part is known as the Dunmore No. 1 and the lower split is called the Dunmore No. 2.
Dunmore No. 2	do	Depth, 520 feet; pillars sound and as shown on maps; rooms walled with gob on both sides of road; conditions good.	76 acres mined. Depth, see section on Plate 9; thickness, 4 feet 6 inches, includes 1 foot bone on top; 1½ feet of bottom rock taken up for height, and chambers nearly full of gob, except center roadway. This bed is known as the No. 3 at Dickson.
Dunmore No. 3	do	Depth, 554 feet; pillars usual size, sound and firm; rooms well filled with gob, except roadway in center; conditions good.	86 acres mined. Depth, see sections on Plate 9; thickness, 4 feet 3 inches, includes 1 foot 1 inch refuse on top; 1½ feet of bottom raised for height; rooms, except roadway, filled with gob. At Dickson and Manville this bed is known as the No. 4, or China bed.

Delaware, Lackawanna & Western Coal Co. collieries.

NATIONAL COLLIERY.

(Works South Scranton section, from Beech Street to city line, and from river to outcrop.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		do	Do.
Four-foot		do	Do.
Diamond		do	Do.
Rock		do	Do.
Big and New County.	No. 7	Big bed eroded under all school property; about over outcrop of New County vein.	73 acres mined. Depth, see section on Plate 20; thickness of Big vein, 12 to 14 feet; of New County, 5 feet; close together and near surface; long since mined and caved; now reopening to reclaim the pillars.
Clark	do	Depth, 72 feet; nearest chamber, 60 feet from lot; now working toward school; not mined under school at present; this bed eroded under the other school properties on the south side.	176 acres mined. Depth, see section on Plate 20; thickness, 4 feet 7 inches, includes 11 inches of refuse; openings large and pillars small and chipping in old workings; in recent workings nearer out crop chambers 25 feet and pillars 26 feet; chambers one-half filled with gob; roadway on side about 10 feet wide; pillars sound.
Dunmore No. 1		Not mined; too thin	This bed here too thin to mine.
Dunmore No. 2	No. 7	Depth, 195 feet; approached to within 40 feet of school; too dangerous to go under school; pillars small and weak, partly crushed; indicate incipient squeeze.	752 acres mined. Depth, see sections on Plates 19, 20, and 21; thickness, 8 feet 6 inches with top bench mined; 2 feet 7 inches contains about 1 foot 4 inches of coal.
	No. 11	Depth, 157 feet; workings open; pillars small but sound; openings large; roof good.	These are mainly very old workings which have been partly remined since old maps were made, hence pillars are not as shown on map. Pillars average small; openings large. In many places pillars are chipped and cracked from pressure. Mines now being resurveyed. No mining under city in this bed at present.
	No. 10	Depth, 96 feet; pillars very small; openings large; gob piers built; roof strong; no caving.	
	No. 8	Depth, 170 feet; mined but inaccessible on account of being filled with water.	
	No. 15	Depth below cellar of school, 11 feet; shaft in school yard, through sandstone; coal pillars small, openings large; 12 sandstone and cement piers 9 feet square; conditions at present good.	
Dunmore No. 3		Thin, and not mined	This bed very thin; not mined.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

DODGE COLLIERY.

(Workings mainly in Taylor Borough. Now opening upper veins in Twenty-second ward of city.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot	No. 43	Eroded	Mainly eroded; may perhaps be present under very small area under highest land.
Five-foot	do	Depth, about 25 feet; not yet mined; preparations to mine now in progress.	Not yet mined; thickness, 2 to 3 feet.
Top split of four-foot	do	Depth, 49 feet; not yet mined; new workings now about 150 feet from the school; chambers will soon extend under school.	Mines now being opened; depth, see sections on plate 18; thickness, 2½ feet; 4½ feet of bottom raised for height.
Underlying veins	do	All underlying beds worked from Bellevue colliery (see p. 27)	Dodge colliery does not operate lower beds under this city.

HAMPTON COLLIERY.

(Works Diamond and Rock veins only. Hyde Park and Keyser Valley, west of South Main and south of Luzerne Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot, four-foot.	No. 32 Annex	See Hyde Park colliery, page 29	Not mined as yet (see Hyde Park colliery, p. 29).
Diamond	do	Depth, 320 feet; worked, and abandoned for a long time, but now remining for bottom coal; pillars reported sound, being reinforced by gob walls from the remining.	561 acres mined. Depth, see sections on Plates 14 to 16; thickness, about 10 to 12 feet; top bench, 6 to 8 feet, formerly mined; now remining for bottom bench, and reinforcing pillars with gob walls; much of mined area long closed by old squeeze.
	No. 31	Depth, 258 feet; caved and inaccessible.	
	No. 19	Depth, 291 feet; caved and inaccessible.	
Rock	No. 22 Annex	Reported inaccessible on account of caves; maps show fair pillar support.	570 acres mined. Depth, see sections on Plates 14 to 16; thickness, 9½ feet, includes 3 feet of refuse; long worked and mostly abandoned; bed squeezed and closed in places; now reclaiming pillars under Keyser Valley.
	No. 19	Depth, 325 feet; caved and inaccessible.	
	No. 31	Depth, 286 feet; caved and inaccessible.	
Big and other lower beds.	No. 32 Annex	Mined at Central and Hyde Park collieries (see pp. 28, 29)	These beds mined by Central and Hyde Park collieries (see pp. 28, 29).

BELLEVUE COLLIERY.

(Works Hyde Park and Bellevue sections from river to South Main Avenue, between Dodge and Oxford mines.)

Eight-foot		Eroded	Eroded.
Five-foot, four-foot		See Dodge colliery, page 26	See Dodge colliery, page 26.
Diamond	No. 12	Depth 13 to 40 feet; dip about 10° NW.; west two-thirds of building on solid pillar; east one-third over workings; large openings and small pillars; now remining for bottom coal; should be properly filled.	234 acres mined. Depth, see sections on Plates 15 and 17; thickness, top bench 6 to 8 feet, with 1½ feet refuse; bottom bench 3 to 6 feet, about one-half refuse; top bench mined years ago and abandoned; now remining the whole area for bottom bench; pillars generally small, but sound; are now reinforced by gob walls as part of the process of remining for bottom bench. The roof in this locality is relatively strong, and in this respect quite different from Providence section.[a]
	No. 13	Depth, 230 feet; inaccessible because crushed	
	No. 29	Eroded	
	No. 32	Depth, 185 feet; on roll; solid under school; conditions good at present.	
	No. 43	Depth, 221 feet; pillars small but sound; now remining for bottom coal and stowing rock and reinforcing pillars with gob walls.	
Rock	No. 13	Depth, 232 feet; approached to about 100 feet from this school; inaccessible farther on account of squeeze.	371 acres mined. Depth, see sections on Plates 15, 17; thickness, 8 feet 9 inches; 3 inches refuse. This vein entirely closed and inaccessible on account of squeeze. Reported to have forced Rock vein pillars down into openings in Big vein, and also affected portions of Diamond bed.[a]
	Nos. 12, 29, 32, 43	Inaccessible on account of old crush	
Big	No. 12	Depth about 145 feet; workings abandoned; openings large; pillars sound; many local falls of top coal in chambers; large pillars under school; could be easily flushed from bore hole.	367 acres mined. Depth, see sections on Plates 15 and 17; thickness, about 18 feet. First mining in either top or bottom bench; then remined in places for remaining bench. This bed closed and inaccessible in many parts of mine, due to breaking down of roof.[a]
	No. 13	Depth, 348 feet; only top bench mined under school, and seam not squeezed here; pillars small for such a thick bed.	
	No. 29	Depth, 131 feet; thickness, 13 feet; bottom bench worked; local falls of top coal and rock under corner of school, but major part of building on large block of solid coal.	
	No. 32	Depth, 325 feet; caved and inaccessible.	
	No. 43	Not mined; access under some of above schools difficult.	
New County	No. 12	Depth, 160 feet; recently mined; endeavoring to columnize pillars	118 acres mined. Depth, see sections on Plates 15 and 17; thickness, about 7 to 8 feet; only about 10 feet below Big vein; pillars generally sound, but not columnized under Big vein; columnization attempted in recent mining.
	No. 13	Depth, about 360 feet; inaccessible on account falls	
	No. 43	Depth, 380 feet; worked from Bellevue; pillars usual size as per maps	
	Nos. 32 and 29	Not mined at present.	

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized, thus permitting pillars of an upper bed to break through the strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

BELLEVUE COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 12	Depth, about 240 feet; nearly solid now; mined under north wall of school; conditions good.	335 acres mined. Depth, see sections on Plates 15 and 17; thickness 7 to 13 feet, with 1 to 2 feet of refuse; first mining in bottom bench; now remining for top bench, in places; pillars generally standing and well distributed; old squeezed portions east of school No. 32, but gangways reopened;[a] conditions generally fair.
	No. 13	Depth, about 400 feet; roof good; no falls; pillars sound and as represented by maps; conditions fair.	
	No. 29	Depth, about 207 feet; approached to 250 feet of school and stopped by local falls; workings reported good condition; rooms, 25 feet; pillars, 25 feet.	
	No. 32	Depth, 475 feet; stands on large pillar under whole lot near crest of roll; conditions good.	
	No. 43	Depth, 430 feet; pillars standing; local falls; conditions fair.	
Dunmore No. 1		Not mined	3 acres mined. Preparations now being made to work this bed.
Dunmore No. 2	No. 12	Depth, 350 feet; mined; condition good	84 acres mined. Depth, see sections on Plates 15 and 17; thickness 5 to 6 feet; pillars usual size, and strong; conditions good throughout.
	No. 43	Not mined	
	No. 13	Depth, about 510 feet; gangway under school; conditions good	
	No. 29	Depth, 320 feet; workings in good condition; pillars sound and usual size.	
	No. 32	Depth, 600 feet; conditions good	
Dunmore No. 3		Not mined	38 acres mined. Opening in preparation for working this bed.

CENTRAL COLLIERY.

(Works Hyde Park section, South Main Avenue and Keyser Valley, south of Washburn Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		Part eroded	Partly eroded.
Four-foot		Part not mined	Balance not mined.
Diamond Rock		Worked from Hampton colliery (see page 26)	See page 26.
Big	No. 32 Annex	Reported caved and inaccessible	362 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 13 to 18 feet; 2 to 3 feet refuse; this vein is generally closed by numerous local falls; pillars doubtless crushed or shattered in some places.[a]
New County	do	Reported flushed and inaccessible	300 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 9 to 10 feet; 2 feet refuse.[a]

Clark	do	Pillars sound, as shown on map; some local falls	370 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 8 feet; 1 foot refuse.
Dunmore No. 1	do	Pillars sound; roof good; hard floor; recently mined; conditions good.	10 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness 4 feet 11 inches coal and 3 feet 1 inch refuse; twin bed—perhaps represents Dunmore Nos. 1 and 2 united.
Dunmore Nos. 2 and 3.		Not mined	Not mined.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY.

(Work Keyser Valley and Hyde Park section to South Main Avenue, between Lafayette Street and Luzerne Street.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 31	Depth, 104 feet; mine just being opened; gangway working toward school, but under school not yet mined; conditions good.	2 acres mined. Depth, see sections on Plates 14 and 16; thickness, 4 feet 8 inches clean coal. This bed extends under Hyde Park section generally, but until recently no mining has been done in it; now being developed from Hyde Park colliery.
	No. 19	Depth, about 140 feet; not yet mined	
Four-foot	No. 31	Depth, about 144 feet; mine just being opened; gangway extending quite close to, but not now under the school; conditions good.	10 acres mined. Depth, see sections on Plates 14 and 16; thickness, 2 feet 10 inches, including 1 inch refuse. This bed extends under the Hyde Park section generally, but until recently has not been mined; now being developed from Hyde Park colliery.
	No. 19	Depth, about 175 feet; not mined	
Diamond	No. 31	Mined from Hampton (see p. 26)	355 acres mined. (See p. 26.)
Rock		Mined from Hampton (see p. 26)	240 acres mined. (See p. 26.)
Big	No. 31	Depth, 374 feet; worked and caved; inaccessible	514 acres mined. Depth, see sections on Plates 14 and 16; thickness, 13 to 18 feet; long mined; caved over large area and workings now abandoned.[a]
	No. 19	Depth, 405 feet; inaccessible; mined and caved	
New County	No. 31	Depth 423 feet; pillars, regular and sound; no indications of settlement; old workings; good roof.	431 acres mined. Depth, see sections on Plates 14 to 16; thickness, 8 to 10 feet, includes 2 feet of refuse; workings in this bed look fair; workings accessible and pillars standing over large areas; no general squeeze; the caves or squeezes are local. Pillars in this and overlying beds are not columnized.[a]
	No. 19	Depth, 440 feet; half of building on solid coal; remainder part mined; pillars fair size; roof and floor good.	
	No. 14	Depth, 397 feet; mine openings filled with gob because of squeeze in progress in 1908; approached on gangway to 50 feet from school lot; all quiet now.	

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 31	Depth, 483 feet; roof, floor, pillars good; gangway, containing flush pipe, under part of lot; chambers under school flushed.	569 acres mined. Depth, see sections on Plates 14 and 16; thickness, 8 feet 8 inches, includes 2 feet refuse; pillars standing and workings in fair condition on major part of this section; now remining in some parts for bottom coal; this causes some chipping of pillars; some local falls and local squeezes.
	No. 19	Depth, about 495 feet; located over basin filled with water; not accessible.	
Dunmore Nos. 1 and 2.	No. 31	Depth, about 529 feet; now opening these beds; not now mined under school, but gangway is approaching; pillars, roof, and floor all good.	8 acres mined. Depth, see sections on Plates 14 and 16; thickness, No. 1 bed, 1½ to 2 feet; dividing rock, 8 feet; No. 2 bed, 3½ feet. Mining under this section in these beds was recently begun and is now developing.
	No. 19	Not mined	
Dunmore No. 3		Not mined in this section	Not mined in this section.

DIAMOND COLLIERY.

(Works North Hyde Park to Providence; river to Keyser Creek, between Pettebone Street and Court Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded under schools	54 acres mined. Depth, see sections on Plate 12; thickness, 8 feet 8 inches, includes 1½-foot refuse. This bed present only under highest part of Hyde Park Hill and Brisbin; has been mined; reclaiming pillars now causing surface subsidence.
Five-foot	No. 20	Depth, 51 feet; mined by Diamond drift	200 acres mined. Depth, see sections on Plate 12; thickness, 5 feet. This has been well mined over from Diamond drift; partly caved and abandoned.
	No. 41	Depth, 60 feet; mined, caved, and inaccessible under both schools	
Four-foot	No. 20	Depth, 89 feet; on solid coal dividing Diamond drift workings and Brisbin workings; over a fault; surrounding pillars fair; fair roof.	42 acres mined. Depth, see sections on Plate 12; thickness, Twin bed 7 to 8 feet, including dividing rock 2½ feet thick; this bed nearly closed, result of Diamond squeeze.
	No. 41	Depth, 115 feet; disturbed by squeeze two years ago; now closed and inaccessible; approached to within about 60 feet of school.	
Diamond	No. 20	Depth, 255 feet; mined, closed, and inaccessible.	630 acres mined. Depth, see sections on Plate 12; thickness, 8 to 12 feet; mined from Diamond shaft; closed by falling roof and general squeeze;[a] now inaccessible.
	No. 21	Eroded	
	No. 41	Depth, 242 feet; closed, caved, and inaccessible.	
Rock	No. 20	Depth, 284 feet	483 acres mined. Depth, see sections on Plate 12; thickness, 8 feet; mined from Diamond shaft; closed by general squeeze; now mining top split in Tripp shaft; hindered by 8 to 15 feet rock.[a]
	No. 41	Depth, 272 feet; caved and inaccessible under both schools	
	No. 21	On outcrop; not mined; too close to surface	

Big	No. 21	Depth, 107 feet; map shows large pillar under school, but mine workings caved and inaccessible.	499 acres mined. Depth, see sections on Plate 12; thickness, 10 to 13 feet; mined from Diamond shaft; closed by general squeeze.[a]
	No. 20	Depth, 345 feet; caved and inaccessible	
	No. 41	Depth, 331 feet; caved and inaccessible	
New County	No. 20	Depth, 400 feet; not mined; nearest work 450 feet distant.	131 acres mined. Depth, see sections on Plate 12; thickness, 5½ feet, includes 1½ feet of refuse; this vein open and working from Diamond shaft; room, 26 feet wide, 50 feet between centers; gob walls both sides of rooms; to dip from school No. 41 the workings are caved and inaccessible.[a]
	No. 2	Depth, 160 feet; not mined.	
	No. 41	Depth, 388 feet; we reached point in workings near school; chambers now being worked toward school; rooms, 26 feet; gob walls both sides.	
Clark	No. 20	Depth, 462 feet.	615 acres mined. Depth, see sections on Plate 12; thickness, 7½ feet, includes 8 inches refuse; largely mined over; disturbed by the general squeeze, and now full of water.
	No. 41	Depth, 440 feet; inaccessible under both schools, on account squeezed area and water.	
	No. 21	See Manville colliery, page 32.	
Dunmore Nos. 1, 2, and 3.		These seams not now mined under any school building.	21 acres mined. Depth, see sections on Plate 12. These beds are 2 to 5 feet thick and are only being mined from Tripp shaft, but workings are of small extent.

BRISBIN COLLIERY.

(Works under Keyser Valley and Hill section, between Hyde Park and Providence.)

Eight-foot		No schools over Brisbin workings	24 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches; mined out and robbed.
Five-foot		do	130 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches.
Four-foot		do	123 acres mined. Depth, see sections on Plate 7; thickness 3 feet.
Diamond		do	Worked from Diamond colliery. (See p. 30.)
Rock		do	182 acres mined. Depth, see sections on Plate 7; thickness, 3 feet 11 inches; mined out and caved.
Big		do	289 acres mined. Depth, see sections on Plate 7; thickness, 10 feet 2 inches; caved and closed.
New County		do	00 acres mined. Too thin to mine, except on mountain side.
Clark		do	404 acres mined. Depth, see sections on Plate 7; thickness, 7 feet 7 inches; caved and closed.
Dunmore Nos. 1, 2, and 3.		do	4 acres mined. Now beginning to be opened.

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 31 No. 19	Depth, 483 feet; roof, floor, pillars good; gangway, containing flush pipe, under part of lot; chambers under school flushed. Depth, about 495 feet; located over basin filled with water; not accessible.	569 acres mined. Depth, see sections on Plates 14 and 16; thickness, 8 feet 8 inches, includes 2 feet refuse; pillars standing and workings in fair condition on major part of this section; now remining in some parts for bottom coal; this causes some chipping of pillars; some local falls and local squeezes.
Dunmore Nos. 1 and 2.	No. 31 No. 19	Depth, about 529 feet; now opening these beds; not now mined under school, but gangway is approaching; pillars, roof, and floor all good. Not mined	8 acres mined. Depth, see sections on Plates 14 and 16; thickness, No. 1 bed, 1½ to 2 feet; dividing rock, 8 feet; No. 2 bed, 3½ feet. Mining under this section in these beds was recently begun and is now developing.
Dunmore No. 3.		Not mined in this section	Not mined in this section.

DIAMOND COLLIERY.

(Works North Hyde Park to Providence; river to Keyser Creek, between Pettebone Street and Court Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded under schools	54 acres mined. Depth, see sections on Plate 12; thickness, 8 feet 8 inches, includes 1½-foot refuse. This bed present only under highest part of Hyde Park Hill and Brisbin; has been mined; reclaiming pillars now causing surface subsidence.
Five-foot	No. 20 No. 41	Depth, 51 feet; mined by Diamond drift Depth, 60 feet; mined, caved, and inaccessible under both schools	200 acres mined. Depth, see sections on Plate 12; thickness, 5 feet. This has been well mined over from Diamond drift; partly caved and abandoned.
Four-foot	No. 20 No. 41	Depth, 89 feet; on solid coal dividing Diamond drift workings and Brisbin workings; over a fault; surrounding pillars fair; fair roof. Depth, 115 feet; disturbed by squeeze two years ago; now closed and inaccessible; approached to within about 60 feet of school.	42 acres mined. Depth, see sections on Plate 12; thickness, Twin bed 7 to 8 feet, including dividing rock 2½ feet thick; this bed nearly closed, result of Diamond squeeze.
Diamond	No. 20 No. 21 No. 41	Depth, 255 feet; mined, closed, and inaccessible Eroded Depth, 242 feet; closed, caved, and inaccessible.	630 acres mined. Depth, see sections on Plate 12; thickness, 8 to 12 feet; mined from Diamond shaft; closed by falling roof and general squeeze; [a] now inaccessible.
Rock	No. 20 No. 41 No. 21	Depth, 284 feet Depth, 272 feet; caved and inaccessible under both schools On outcrop; not mined; too close to surface	483 acres mined. Depth, see sections on Plate 12; thickness, 8 feet; mined from Diamond shaft; closed by general squeeze; now mining top split in Tripp shaft; hindered by 8 to 15 feet rock.[a]

Big	No. 21	Depth, 107 feet; map shows large pillar under school, but mine workings caved and inaccessible.	499 acres mined. Depth, see sections on Plate 12; thickness, 10 to 13 feet; mined from Diamond shaft; closed by general squeeze.[a]
	No. 20	Depth, 345 feet; caved and inaccessible	
	No. 41	Depth, 331 feet; caved and inaccessible	
New County	No. 20	Depth, 400 feet; not mined; nearest work 450 feet distant.	131 acres mined. Depth, see sections on Plate 12; thickness, 5½ feet, includes 1½ feet of refuse; this vein open and working from Diamond shaft; room, 26 feet wide, 50 feet between centers; gob walls both sides of rooms; to dip from school No. 41 the workings are caved and inaccessible.[a]
	No. 2	Depth, 160 feet; not mined.	
	No. 41	Depth, 388 feet; we reached point in workings near school; chambers now being worked toward school; rooms, 26 feet; gob walls both sides.	
Clark	No. 20	Depth, 462 feet	615 acres mined. Depth, see sections on Plate 12; thickness, 7½ feet, includes 8 inches refuse; largely mined over; disturbed by the general squeeze, and now full of water.
	No. 41	Depth, 440 feet; inaccessible under both schools, on account squeezed area and water.	
	No. 21	See Manville colliery, page 32	
Dunmore Nos. 1, 2, and 3.		These seams not now mined under any school building	21 acres mined. Depth, see sections on Plate 12. These beds are 2 to 5 feet thick and are only being mined from Tripp shaft, but workings are of small extent.

BRISBIN COLLIERY.

(Works under Keyser Valley and Hill section, between Hyde Park and Providence.)

Eight-foot		No schools over Brisbin workings	24 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches; mined out and robbed.
Five-foot		do	130 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches.
Four-foot		do	123 acres mined. Depth, see sections on Plate 7; thickness 3 feet.
Diamond		do	Worked from Diamond colliery. (See p. 30.)
Rock		do	182 acres mined. Depth, see sections on Plate 7; thickness, 3 feet 11 inches; mined out and caved.
Big		do	289 acres mined. Depth, see sections on Plate 7; thickness, 10 feet 2 inches; caved and closed.
New County		do	00 acres mined. Too thin to mine, except on mountain side.
Clark		do	404 acres mined. Depth, see sections on Plate 7; thickness, 7 feet 7 inches; caved and closed.
Dunmore Nos. 1, 2, and 3.		do	4 acres mined. Now beginning to be opened.

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

CAYUGA COLLIERY AND STORRS COLLIERY.

(Work section between Keyser Valley and Leggetts Creek, from Bloom Avenue to foot of West Mountain.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot	No. 22	Depth, 36 feet; solid block coal under school	268 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet 8 inches, includes 8 inches of refuse; pillars now being removed; space stowed with gob and surplus rock from a lower bed.
Four-foot	do	Depth, about 124 feet; mined, but inaccessible on account of danger due to falling roof.	168 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet, includes 8 inches of refuse; falling roof, 2½ feet thick, closes the mine after standing; now mining top split of Four-foot, 20 inches thick, and stowing surplus rock in 5-foot vein.
Diamond	do	Depth, 186 feet; approached to 60 feet from school; pillars sound and of fair size; openings closed by falling roof; roof will not stand after timbers rot; pillars do not crush.	490 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 8 inches refuse; caved in many places; bad fire-clay roof which falls soon after working stops; pillars strong.[a]
Rock	do	Depth, 280 feet; pillars sound; rooms gobbed on one side; conditions good.	174 acres mined. Depth, see sections on Plates 11 and 13; thickness, 3 feet 3 inches clear; taking down 2½ feet of roof for height; roof good; conditions fair.
Big	do	Depth, 317 feet; caved, closed, and inaccessible	623 acres mined. Depth, see sections on Plates 11 and 13; thickness, 10 feet, 1 foot 3 inches refuse; old mine caved and closed.
New County		Not mined; too thin	Not mined; too thin.
Clark	do	Depth, 476 feet. This section of working flushed to within 2½ feet of roof; flushing still in progress.	576 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 2 inches refuse; many local falls, but no general squeeze; workings now being flushed with culm.
	No. 23	Depth, 423 feet; mined but not accessible	
Dunmore No. 1		Not mined	Not mined, but now being opened.
Dunmore No. 2		do	Not mined; opening in preparation.
Dunmore No. 3		do	Do.

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized; the pillars of an upper bed are thus permitted to break through the strata which separate the seams into the chambers or openings of an underlying bed.

People's Coal Co.

OXFORD COLLIERY.

(Works Hyde Park section, from the river to South Main Avenue, between Lackawanna and Luzerne Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot, four-foot		Not mined	Not mined at present.
Diamond	No. 14	Depth, 252 feet; approached to point under northwest corner of building; solid pillar under rest of school lot; bed, 10 feet thick; falls in room approaching school; conditions good.	84 acres mined. Depth, see sections on Plate 17; thickness, 10 to 15 feet; original workings in top bench, 3 to 6 feet, with about 2½ feet refuse; over 5 acres caved under No. 16 School; pillars outside of cave apparently sound;[a] no indications of future caving; gob piers built under vicinity of Lackawanna Railroad Co.'s bridge and Lackawanna Avenue.
	No. 16	Depth, 200 feet; caved and inaccessible; approached to edge of coal worked by Bridge Coal Co.	
Rock	No. 14	Depth, 294 feet; inaccessible; worked from Hampton colliery	104 acres mined. Depth, see sections on Plate 17; thickness, 8 feet 2 inches, with 1 inch refuse; over 5 acres caved under No. 16 School; pillars sound surrounding cave, and no indications of spread of cave;[a] parts of Oxford working effectually flushed with culm.
	No. 16	Depth, 229 feet; caved and inaccessible; worked by Bridge Coal Co.	
Big	No. 14	Depth, about 364 feet; inaccessible, caved, and flushed	116 acres mined. Depth, see sections on Plate 17; thickness, 12 to 18 feet, with 2 to 3 feet of refuse; pillars and chambers of usual size; local falls, but no serious chipping or other indications of extension of cave, beyond 1 or 2 acres under Schoo lNo. 16.[a]
	No. 16	Depth, 289 feet; inaccessible on account of cave; pillars surrounding cave appear in fair condition and usual size; a few local falls, but no indications of extension of caving; worked by Bridge Coal Co.	
New County	No. 14	See Hyde Park colliery, page 29	120 acres mined. Depth, see sections on Plate 17; thickness, 7 to 10 feet, with 1 to 2 feet of refuse; partly flushed; pillars standing, strong; roof good; no present indication of squeezing;[a] no caving under No. 16 School.
	No. 16	Depth, about 334 feet; pillars standing in good condition and well distributed; no local falls; no present indication of settlement.	
Clark	No. 14	Depth, 435 feet; approached to within 250 feet of school; now inaccessible account local falls and flushing.	104 acres mined. Depth, see sections on Plate 17; thickness, 7 to 13 feet, about 2 feet refuse; openings large, but pillars firm, with fair distribution; slight chipping, but no present indications of subsidence.
	No. 16	Depth, 370 feet; recently unwatered, and now accessible; pillars standing in good condition except for slight chipping; local falls in chamber under this school; old timber cogs standing, but bearing no weight; mined by Bridge Coal Co.	

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

People's Coal Co.—Continued.

OXFORD COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 1	No. 14	Depth, 516 feet; mined under northeast and southeast side, but major part solid; chambers well filled with gob, and mining stopped.	21 acres mined. Depth, see sections on Plate 17; thickness, 1 foot of coal, 2 feet of rock, 2½ feet of coal; rock and top bench taken down for height in roads; chambers, 30 feet; pillars, 18 to 20 feet; openings well filled with gob; fairly successful attempt made to columnize the pillars in the Dunmore beds.
	No. 16	Depth, 481 feet; not mined.	
Dunmore No. 2	No. 14	Depth, 567 feet; heading and airway under central and eastern part of building; western part of building over solid coal; recently mined; chambers well filled with gob.	73 acres mined. Depth, see sections on Plate 17; thickness, about 4½ feet, with 6 inches of refuse; roof taken down for roads, and rooms well packed with gob; pillars fairly well columnized.
	No. 16	Depth, 502 feet; not mined under school lot; mined from east side of Chestnut Street westward.	
Dunmore No. 3	No. 14	Depth, 620 feet; gangway and airway under central and eastern part of building; western corner on solid coal; recently mined.	62 acres mined. Depth, see sections on Plate 17; thickness, about 4 feet 10 inches, with 1¼ feet of refuse; recently mined, and pillars fairly well columnized; rooms filled with gob, except in roadways.
	No. 16	Depth, 568 feet; mined from westward only, up to line of school lot; not mined under the lot; mining stopped here.	

Delaware & Hudson Canal Co. collieries.

VON STORCH COLLIERY.

(Works Providence section, river to mountain, between Clearview and Putnam Streets, from river to Cayuga line, between Putnam and William.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		No schools	Worked and robbed.
Five-foot	No. 24 No. 25	Depth, 55 feet; pillars sound; conditions fair. Depth, 37 feet; large pillar under entire school lot.	104 acres mined. Depth, see sections on Plates 7 and 8; thickness, 4 feet 9 inches; 1 inch of refuse; fireclay roof, which falls; pillars well distributed and look good; rooms well packed with gob, inclusive of roadways when finished.
Four-foot	No. 24 No. 40 No. 25	Depth, 147 feet; inaccessible; all openings filled with gob See West Ridge colliery, page 23. Large pillars under half of school lot; mined under other half; chambers filled; much pressure on pillars from effect of squeezing in Dunmore bed; passageway along east side of Big pillar.	165 acres mined. Depth, see sections on Plates 7 and 8; thickness 3 feet clear; chambers well filled with gob; many parts roadway also filled.
Diamond		Caved; abandoned; inaccessible	365 acres mined. Depth, see sections on Plates 7 and 8; thickness, 10 to 15 feet, includes 2 to 4 feet refuse. This bed carries 10 to 15 feet of falling fireclay roof which soon disintegrates and falls, filling all openings.
Rock	No. 24 No. 40 No. 25	Depth, 235 feet; solid, and too thin to mine here Depth, 260 feet; caved and closed. Depth, 216 feet; solid under school lot; mined on west side only at present; vicinity of School No. 25 shows signs of squeeze.	395 acres mined. Depth, see sections on Plates 7 and 8; thickness, 3 feet 6 inches; 2 inches of refuse; falling roof; rooms filled with gob and falling roof.
Big		Caved and closed	397 acres mined. Depth, see sections on Plates 7 and 8; thickness, 11 to 13 feet; closed throughout.
New County		Not mined; to date considered too thin to mine	6 acres mined.
Clark		Caved and closed	489 acres mined. Depth, see sections on Plates 7 and 8; thickness, 7 to 9 feet; caved and closed throughout.
Dunmore beds		These beds mined by West Ridge colliery (see p. 23). No. 40 School undermined from this colliery in Diamond, Big, and Clark beds, but workings are caved and closed.	

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

BELLEVUE COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 12	Depth, about 240 feet; nearly solid now; mined under north wall of school; conditions good.	335 acres mined. Depth, see sections on Plates 15 and 17; thickness 7 to 13 feet, with 1 to 2 feet of refuse; first mining in bottom bench; now remining for top bench, in places; pillars generally standing and well distributed; old squeezed portions east of school No. 32, but gangways reopened;[a] conditions generally fair.
	No. 13	Depth, about 400 feet; roof good; no falls; pillars sound and as represented by maps; conditions fair.	
	No. 29	Depth, about 207 feet; approached to 250 feet of school and stopped by local falls; workings reported good condition; rooms, 25 feet; pillars, 25 feet.	
	No. 32	Depth, 475 feet; stands on large pillar under whole lot near crest of roll; conditions good.	
	No. 43	Depth, 430 feet; pillars standing; local falls; conditions fair.	
Dunmore No. 1		Not mined	3 acres mined. Preparations now being made to work this bed.
Dunmore No. 2	No. 12	Depth, 350 feet; mined; condition good	84 acres mined. Depth, see sections on Plates 15 and 17; thickness 5 to 6 feet; pillars usual size, and strong; conditions good throughout.
	No. 43	Not mined	
	No. 13	Depth, about 510 feet; gangway under school; conditions good	
	No. 29	Depth, 320 feet; workings in good condition; pillars sound and usual size.	
	No. 32	Depth, 600 feet; conditions good	
Dunmore No. 3		Not mined	38 acres mined. Opening in preparation for working this bed.

CENTRAL COLLIERY.

(Works Hyde Park section, South Main Avenue and Keyser Valley, south of Washburn Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		Part eroded	Partly eroded.
Four-foot		Part not mined	Balance not mined.
Diamond Rock		Worked from Hampton colliery (see page 26)	See page 26.
Big	No. 32 Annex	Reported caved and inaccessible	362 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 13 to 18 feet; 2 to 3 feet refuse; this vein is generally closed by numerous local falls; pillars doubtless crushed or shattered in some places.[a]
New County	do	Reported flushed and inaccessible	300 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 9 to 10 feet; 2 feet refuse.[a]

Clark	do	Pillars sound, as shown on map; some local falls	370 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 8 feet; 1 foot refuse.
Dunmore No. 1	do	Pillars sound; roof good; hard floor; recently mined; conditions good.	10 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness 4 feet 11 inches coal and 3 feet 1 inch refuse; twin bed—perhaps represents Dunmore Nos. 1 and 2 united.
Dunmore Nos. 2 and 3.		Not mined	Not mined.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY.

(Work Keyser Valley and Hyde Park section to South Main Avenue, between Lafayette Street and Luzerne Street.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 31	Depth, 104 feet; mine just being opened; gangway working toward school, but under school not yet mined; conditions good.	2 acres mined. Depth, see sections on Plates 14 and 16; thickness, 4 feet 8 inches clean coal. This bed extends under Hyde Park section generally, but until recently no mining has been done in it; now being developed from Hyde Park colliery.
	No. 19	Depth, about 140 feet; not yet mined	
Four-foot	No. 31	Depth, about 144 feet; mine just being opened; gangway extending quite close to, but not now under the school; conditions good.	10 acres mined. Depth, see sections on Plates 14 and 16; thickness, 2 feet 10 inches, including 1 inch refuse. This bed extends under the Hyde Park section generally, but until recently has not been mined; now being developed from Hyde Park colliery.
	No. 19	Depth, about 175 feet; not mined	
Diamond	No. 31	Mined from Hampton (see p. 26)	355 acres mined. (See p. 26.)
Rock		Mined from Hampton (see p. 26)	240 acres mined. (See p. 26.)
Big	No. 31	Depth, 374 feet; worked and caved; inaccessible	514 acres mined. Depth, see sections on Plates 14 and 16; thickness, 13 to 18 feet; long mined; caved over large area and workings now abandoned.[a]
	No. 19	Depth, 405 feet; inaccessible; mined and caved	
New County	No. 31	Depth 423 feet; pillars, regular and sound; no indications of settlement; old workings; good roof.	431 acres mined. Depth, see sections on Plates 14 to 16; thickness, 8 to 10 feet, includes 2 feet of refuse; workings in this bed look fair; workings accessible and pillars standing over large areas; no general squeeze; the caves or squeezes are local. Pillars in this and overlying beds are not columnized.[a]
	No. 19	Depth, 440 feet; half of building on solid coal; remainder part mined; pillars fair size; roof and floor good.	
	No. 14	Depth, 397 feet; mine openings filled with gob because of squeeze in progress in 1908; approached on gangway to 50 feet from school lot; all quiet now.	

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 31	Depth, 483 feet; roof, floor, pillars good; gangway, containing flush pipe, under part of lot; chambers under school flushed.	569 acres mined. Depth, see sections on Plates 14 and 16; thickness, 8 feet 8 inches, includes 2 feet refuse; pillars standing and workings in fair condition on major part of this section; now remining in some parts for bottom coal; this causes some chipping of pillars; some local falls and local squeezes.
	No. 19	Depth, about 495 feet; located over basin filled with water; not accessible.	
Dunmore Nos. 1 and 2.	No. 31	Depth, about 529 feet; now opening these beds; not now mined under school, but gangway is approaching; pillars, roof, and floor all good.	8 acres mined. Depth, see sections on Plates 14 and 16; thickness, No. 1 bed, 1½ to 2 feet; dividing rock, 8 feet; No. 2 bed, 3½ feet. Mining under this section in these beds was recently begun and is now developing.
	No. 19	Not mined	
Dunmore No. 3		Not mined in this section	Not mined in this section.

DIAMOND COLLIERY.

(Works North Hyde Park to Providence; river to Keyser Creek, between Pettebone Street and Court Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded under schools	54 acres mined. Depth, see sections on Plate 12; thickness, 8 feet 8 inches, includes 1½-foot refuse. This bed present only under highest part of Hyde Park Hill and Brisbin; has been mined; reclaiming pillars now causing surface subsidence.
Five-foot	No. 20	Depth, 51 feet; mined by Diamond drift	200 acres mined. Depth, see sections on Plate 12; thickness, 5 feet. This has been well mined over from Diamond drift; partly caved and abandoned.
	No. 41	Depth, 60 feet; mined, caved, and inaccessible under both schools	
Four-foot	No. 20	Depth, 89 feet; on solid coal dividing Diamond drift workings and Brisbin workings; over a fault; surrounding pillars fair; fair roof.	42 acres mined. Depth, see sections on Plate 12; thickness, Twin bed 7 to 8 feet, including dividing rock 2½ feet thick; this bed nearly closed, result of Diamond squeeze.
	No. 41	Depth, 115 feet; disturbed by squeeze two years ago; now closed and inaccessible; approached to within about 60 feet of school.	
Diamond	No. 20	Depth, 255 feet; mined, closed, and inaccessible	630 acres mined. Depth, see sections on Plate 12; thickness, 8 to 12 feet; mined from Diamond shaft; closed by falling roof and general squeeze;[a] now inaccessible.
	No. 21	Eroded	
	No. 41	Depth, 242 feet; closed, caved, and inaccessible.	
Rock	No. 20	Depth, 284 feet	483 acres mined. Depth, see sections on Plate 12; thickness, 8 feet; mined from Diamond shaft; closed by general squeeze; now mining top split in Tripp shaft; hindered by 8 to 15 feet rock.[a]
	No. 41	Depth, 272 feet; caved and inaccessible under both schools	
	No. 21	On outcrop; not mined; too close to surface	

Big	No. 21	Depth, 107 feet; map shows large pillar under school, but mine workings caved and inaccessible.	499 acres mined. Depth, see sections on Plate 12; thickness, 10 to 13 feet; mined from Diamond shaft; closed by general squeeze.[a]
	No. 20	Depth, 345 feet; caved and inaccessible	
	No. 41	Depth, 331 feet; caved and inaccessible	
New County	No. 20	Depth, 400 feet; not mined; nearest work 450 feet distant	131 acres mined. Depth, see sections on Plate 12; thickness, 5½ feet, includes 1½ feet of refuse; this vein open and working from Diamond shaft; room, 26 feet wide, 50 feet between centers; gob walls both sides of rooms; to dip from school No. 41 the workings are caved and inaccessible.[a]
	No. 2	Depth, 160 feet; not mined	
	No. 41	Depth, 388 feet; we reached point in workings near school; chambers now being worked toward school; rooms, 26 feet; gob walls both sides.	
Clark	No. 20	Depth, 462 feet	615 acres mined. Depth, see sections on Plate 12; thickness, 7½ feet, includes 8 inches refuse; largely mined over; disturbed by the general squeeze, and now full of water.
	No. 41	Depth, 440 feet; inaccessible under both schools, on account squeezed area and water.	
	No. 21	See Manville colliery, page 32	
Dunmore Nos. 1, 2, and 3.		These seams not now mined under any school building	21 acres mined. Depth, see sections on Plate 12. These beds are 2 to 5 feet thick and are only being mined from Tripp shaft, but workings are of small extent.

BRISBIN COLLIERY.

(Works under Keyser Valley and Hill section, between Hyde Park and Providence.)

Eight-foot		No schools over Brisbin workings	24 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches; mined out and robbed.
Five-foot		do	130 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches.
Four-foot		do	123 acres mined. Depth, see sections on Plate 7; thickness 3 feet.
Diamond		do	Worked from Diamond colliery. (See p. 30.)
Rock		do	182 acres mined. Depth, see sections on Plate 7; thickness, 3 feet 11 inches; mined out and caved.
Big		do	289 acres mined. Depth, see sections on Plate 7; thickness, 10 feet 2 inches; caved and closed.
New County		do	00 acres mined. Too thin to mine, except on mountain side.
Clark		do	404 acres mined. Depth, see sections on Plate 7; thickness, 7 feet 7 inches; caved and closed.
Dunmore Nos. 1, 2, and 3.		do	4 acres mined. Now beginning to be opened.

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

CAYUGA COLLIERY AND STORRS COLLIERY.

(Work section between Keyser Valley and Leggetts Creek, from Bloom Avenue to foot of West Mountain.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot	No. 22	Depth, 36 feet; solid block coal under school	268 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet 8 inches, includes 8 inches of refuse; pillars now being removed; space stowed with gob and surplus rock from a lower bed.
Four-foot	do	Depth, about 124 feet; mined, but inaccessible on account of danger due to falling roof.	168 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet, includes 8 inches of refuse; falling roof, 2½ feet thick, closes the mine after standing; now mining top split of Four-foot, 20 inches thick, and stowing surplus rock in 5-foot vein.
Diamond	do	Depth, 186 feet; approached to 60 feet from school; pillars sound and of fair size; openings closed by falling roof; roof will not stand after timbers rot; pillars do not crush.	490 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 8 inches refuse; caved in many places; bad fire-clay roof which falls soon after working stops; pillars strong.[a]
Rock	do	Depth, 280 feet; pillars sound; rooms gobbed on one side; conditions good.	174 acres mined. Depth, see sections on Plates 11 and 13; thickness, 3 feet 3 inches clear; taking down 2½ feet of roof for height; roof good; conditions fair.
Big	do	Depth, 317 feet; caved, closed, and inaccessible	623 acres mined. Depth, see sections on Plates 11 and 13; thickness, 10 feet, 1 foot 3 inches refuse; old mine caved and closed.
New County		Not mined; too thin	Not mined; too thin.
Clark	do	Depth, 476 feet. This section of working flushed to within 2½ feet of roof; flushing still in progress.	576 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 2 inches refuse; many local falls, but no general squeeze; workings now being flushed with culm.
	No. 23	Depth, 423 feet; mined but not accessible	
Dunmore No. 1		Not mined	Not mined, but now being opened.
Dunmore No. 2		do	Not mined; opening in preparation.
Dunmore No. 3		do	Do.

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[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized; the pillars of an upper bed are thus permitted to break through the strata which separate the seams into the chambers or openings of an underlying bed.

People's Coal Co.

OXFORD COLLIERY.

(Works Hyde Park section, from the river to South Main Avenue, between Lackawanna and Luzerne Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot, four-foot		Not mined	Not mined at present.
Diamond	No. 14	Depth, 252 feet; approached to point under northwest corner of building; solid pillar under rest of school lot; bed, 10 feet thick; falls in room approaching school; conditions good.	84 acres mined. Depth, see sections on Plate 17; thickness, 10 to 15 feet; original workings in top bench, 3 to 6 feet, with about 2½ feet refuse; over 5 acres caved under No. 16 School; pillars outside of cave apparently sound;[a] no indications of future caving; gob piers built under vicinity of Lackawanna Railroad Co.'s bridge and Lackawanna Avenue.
	No. 16	Depth, 200 feet; caved and inaccessible; approached to edge of coal worked by Bridge Coal Co.	
Rock	No. 14	Depth, 294 feet; inaccessible; worked from Hampton colliery	104 acres mined. Depth, see sections on Plate 17; thickness, 8 feet 2 inches, with 1 inch refuse; over 5 acres caved under No. 16 School; pillars sound surrounding cave, and no indications of spread of cave;[a] parts of Oxford working effectually flushed with culm.
	No. 16	Depth, 229 feet; caved and inaccessible; worked by Bridge Coal Co.	
Big	No. 14	Depth, about 364 feet; inaccessible, caved, and flushed	116 acres mined. Depth, see sections on Plate 17; thickness, 12 to 18 feet, with 2 to 3 feet of refuse; pillars and chambers of usual size; local falls, but no serious chipping or other indications of extension of cave, beyond 1 or 2 acres under School No. 16.[a]
	No. 16	Depth, 289 feet; inaccessible on account of cave; pillars surrounding cave appear in fair condition and usual size; a few local falls, but no indications of extension of caving; worked by Bridge Coal Co.	
New County	No. 14	See Hyde Park colliery, page 29	120 acres mined. Depth, see sections on Plate 17; thickness, 7 to 10 feet, with 1 to 2 feet of refuse; partly flushed; pillars standing, strong; roof good; no present indication of squeezing;[a] no caving under No. 16 School.
	No. 16	Depth, about 334 feet; pillars standing in good condition and well distributed; no local falls; no present indication of settlement.	
Clark	No. 14	Depth, 435 feet; approached to within 250 feet of school; now inaccessible account local falls and flushing.	104 acres mined. Depth, see sections on Plate 17; thickness, 7 to 13 feet, about 2 feet refuse; openings large, but pillars firm, with fair distribution; slight chipping, but no present indications of subsidence.
	No. 16	Depth, 370 feet; recently unwatered, and now accessible; pillars standing in good condition except for slight chipping; local falls in chamber under this school; old timber cogs standing, but bearing no weight; mined by Bridge Coal Co.	

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

People's Coal Co.—Continued.

OXFORD COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 1	No. 14	Depth, 516 feet; mined under northeast and southeast side, but major part solid; chambers well filled with gob, and mining stopped.	21 acres mined. Depth, see sections on Plate 17; thickness, 1 foot of coal, 2 feet of rock, 2½ feet of coal; rock and top bench taken down for height in roads; chambers, 30 feet; pillars, 18 to 20 feet; openings well filled with gob; fairly successful attempt made to columnize the pillars in the Dunmore beds.
	No. 16	Depth, 481 feet; not mined.	
Dunmore No. 2	No. 14	Depth, 567 feet; heading and airway under central and eastern part of building; western part of building over solid coal; recently mined; chambers well filled with gob.	73 acres mined. Depth, see sections on Plate 17; thickness, about 4½ feet, with 6 inches of refuse; roof taken down for roads, and rooms well packed with gob; pillars fairly well columnized.
	No. 16	Depth, 502 feet; not mined under school lot; mined from east side of Chestnut Street westward.	
Dunmore No. 3	No. 14	Depth, 620 feet; gangway and airway under central and eastern part of building; western corner on solid coal; recently mined.	62 acres mined. Depth, see sections on Plate 17; thickness, about 4 feet 10 inches, with 1¾ feet of refuse; recently mined, and pillars fairly well columnized; rooms filled with gob, except in roadways.
	No. 16	Depth, 568 feet; mined from westward only, up to line of school lot; not mined under the lot; mining stopped here.	

Delaware & Hudson Canal Co. collieries.

VON STORCH COLLIERY.

(Works Providence section, river to mountain, between Clearview and Putnam Streets, from river to Cayuga line, between Putnam and William.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		No schools	Worked and robbed.
Five-foot	No. 24	Depth, 55 feet; pillars sound; conditions fair.	104 acres mined. Depth, see sections on Plates 7 and 8; thickness, 4 feet 9 inches; 1 inch of refuse; fireclay roof, which falls; pillars well distributed and look good; rooms well packed with gob, inclusive of roadways when finished.
	No. 25	Depth, 37 feet; large pillar under entire school lot.	
Four-foot	No. 24	Depth, 147 feet; inaccessible; all openings filled with gob	165 acres mined. Depth, see sections on Plates 7 and 8; thickness 3 feet clear; chambers well filled with gob; many parts roadway also filled.
	No. 40	See West Ridge colliery, page 23.	
	No. 25	Large pillars under half of school lot; mined under other half; chambers filled; much pressure on pillars from effect of squeezing in Dunmore bed; passageway along east side of Big pillar.	
Diamond		Caved; abandoned; inaccessible	365 acres mined. Depth, see sections on Plates 7 and 8; thickness, 10 to 15 feet, includes 2 to 4 feet refuse. This bed carries 10 to 15 feet of falling fireclay roof which soon disintegrates and falls, filling all openings.
Rock	No. 24	Depth, 235 feet; solid, and too thin to mine here	395 acres mined. Depth, see sections on Plates 7 and 8; thickness, 3 feet 6 inches; 2 inches of refuse; falling roof; rooms filled with gob and falling roof.
	No. 40	Depth, 260 feet; caved and closed.	
	No. 25	Depth, 216 feet; solid under school lot; mined on west side only at present; vicinity of School No. 25 shows signs of squeeze.	
Big		Caved and closed	397 acres mined. Depth, see sections on Plates 7 and 8; thickness, 11 to 13 feet; closed throughout.
New County		Not mined; to date considered too thin to mine	6 acres mined.
Clark		Caved and closed	489 acres mined. Depth, see sections on Plates 7 and 8; thickness, 7 to 9 feet; caved and closed throughout.
Dunmore beds		These beds mined by West Ridge colliery (see p. 23). No. 40 School undermined from this colliery in Diamond, Big, and Clark beds, but workings are caved and closed.	

Delaware & Hudson Canal Co. collieries—Continued.

LEGGETTS CREEK COLLIERY.

(Works north Providence section, bounded by East Market Street, North Main Avenue, and the city line.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot	No. 44	Worked out and abandoned	33 acres mined. Depth, see sections on Plates 10 and 11; thickness, 3 feet 6 inches to 5 feet; worked out and abandoned.
	No. 26	Eroded.	
Four-foot	No. 26	Depth, 66 feet; inaccessible; filled with rock or gangway fallen	263 acres mined. Depth, see sections on Plates 10 and 11; thickness, 3 feet 6 inches; chambers well filled with gob.
	No. 44	Accessible; pillars sound; conditions fair.	
Diamond	No. 24	Depth, 212 feet; caved, closed, and abandoned	263 acres mined. Depth, see sections on Plates 10 and 11; thickness, 8 feet to 10 feet; carries 10 to 15 feet of falling roof of fireclay and shale which has fallen and closed all openings throughout.
	No. 26	Depth, 135 feet; caved, closed and abandoned.	
	No. 44	Caved, closed, and abandoned.	
Rock	No. 24	Depth, 235 feet; not yet mined	98 acres mined. Depth, see sections on Plates 10 and 11; thickness, 2½ to 3 feet; rooms well filled with gob on both sides; conditions fair.
	No. 26	Depth, 172 feet; rooms filled with gob both sides of roadway; pillars sound; roof strong.	
	No. 44	Now extended under school; cob walls both sides; no signs at present of squeeze in Dunmore bed; conditions fair.	
Big		This bed flushed under School No. 26 and caved and closed under Nos. 24, 25, and 44; west half of School No. 25 is over solid pillar in all veins.	375 acres mined. Depth, see sections on Plates 10 and 11; thickness, 11 to 12 feet; mined and abandoned long ago; now caved and closed.
New County		Too thin to mine	Not mined; too thin.
		This bed reported closed under all schools	296 acres mined. Depth, see sections on Plates 10 and 11; thickness, 8 feet; mined, abandoned, and closed.
	No. 26	See Dickson colliery, page 38.	
Dunmore No. 1		Not mined; too thin	Not mined; too thin. Bottom split of Dunmore No. 1 is here known as Dunmore No. 2.
Dunmore No. 2	No. 26	Depth, 531 feet; very thin; not worked	51 acres mined. Depth, see sections on Plates 10 and 11; thickness, 1 to 2½ feet; only small area mined where thickest. This bed at this colliery is known as No. 3.
	No. 44	2½ feet thick; rooms filled with gob.	
Dunmore No. 3 (here known as No. 4).	No. 24	Depth, 670 feet; pillars sound; roof sound; rooms stowed with rock; conditions fair.	333 acres mined. Depth, see sections on Plates 10 and 11; thickness, 4½ feet, with about 1 foot of refuse on top; rooms fair, all gobbed with rock; pillars not sufficiently large or strong to sustain pressure of roof, consequently squeezing is in progress; roof hard and strong, which remains intact after squeeze. This bed is here known as No. 4 Dunmore.
	No. 25	Depth about 653 feet; solid pillar under west half of school; this pillar now affected more or less by a squeeze approaching from the eastward in this bed.	
	No. 26	Depth 573 feet; no signs of squeeze here at present; flush pipe laid from Von Storch breaker to flush this locality, which, judging from experience, is liable to squeeze.	
	No. 44	Closed by squeeze and inaccessible.	

MARVINE COLLIERY.

(Works between Providence and the city line, from Florida Street to Dunmore and Olyphant Road.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 44	Near surface; worked out and abandoned years ago	150 acres mined. Depth, see sections on Plates 9 and 10; thickness, 5 to 8 feet, includes 2 to 3 feet of refuse; bottom bench, 5 feet thick, mined only; this bed mined from Richmond drifts; abandoned and inaccessible.
Four-foot		Operated from Leggetts Creek colliery (see p. 36)	See page 36.
Diamond	No. 44	See Leggetts Creek colliery, page 36	135 acres mined. Depth, see sections on Plates 8 and 10; thickness, 9 to 10 feet; bad falling fireclay roof; now being mined under Marvine farm on east side of mine; on west side now reopening caved area caused by recent general squeeze.
Rock	do	See Leggetts Creek colliery, page 36	This vein not mined at Marvine colliery.
Big	do	Mined, abandoned, and caved	445 acres mined. Depth, see sections on Plates 9 and 10; thickness, 13 to 14 feet; divides into two splits on east side, where it is now being worked under Marvine farm where there are few surface improvements.
New County		Not mined; too thin	Too thin to mine.
Clark	No. 44	Worked from Leggetts Creek colliery (see p. 36)	242 acres mined. Depth, see sections on Plates 9 and 10; thickness, 5 to 6 feet; largely caved and closed on west side; open and partly mined on east side; few improvements on surface east side.
Dunmore No. 1	do	See Leggetts Creek colliery, page 36	Too thin to mine.
Dunmore No. 2			53 acres mined. Depth, see sections on Plates 9 and 10; thickness, 2½ to 3 feet; not much mined as yet.
Dunmore No. 3		No schools over the Marvine workings	74 acres mined. Depth, see sections on Plates 9 and 10; thickness, 4½ feet, includes 1 foot of refuse. These workings have suffered by general squeeze on west side at Marvine; squeeze has more or less affected overlying beds and has extended to Leggetts Creek mine; now working under good conditions on east side under Marvine farm.

Delaware & Hudson Canal Co. collieries—Continued.

DICKSON COLLIERY.

(Works Green Ridge section from the river to the Dunmore line and from Delaware Street to Columbia Avenue.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
All beds above Big		Eroded	Eroded.
Big	No. 27	Just over the line on Pennsylvania Coal Co. land and not undermined.	101 acres mined. Depth, see sections on Plates 6 and 8; thickness 12 feet; includes 2 feet 4 inches of refuse; workings stopped account thin cover of sand and gravel; standing pillars fair.
New County		Contains too much refuse to mine at present. About 5 feet thick.	
Clark	No. 27	Depth, 226 feet; this school on Pennsylvania Coal Co. land, near land line; not mined; roll passes under school.	194 acres mined. Depth, see sections on Plates 6 to 8; thickness of 8 feet includes 9 inches of refuse; pillars standing in fair condition; local falls, but no squeeze as yet.
Dunmore No. 1	do	Depth, 289 feet; near to land line on Pennsylvania Coal Co. land; not mined.	83 acres mined. Depth, see sections on Plates 6 and 8; thickness, 2 feet 2 inches; well mined over; rooms well gobbed; pillars sound; conditions fair. This is bottom split of the bed and is here known as Dunmore No. 2, top split being called No. 1.
Dunmore No. 2	do	Just over line on Pennsylvania Coal Co. land; not mined.	50 acres mined. Depth, see sections on Plates 6 and 8; bed rather thin, and therefore not extensively mined; where mined, rooms filled and conditions fair; here known as Dunmore No. 3.
Dunmore No. 3	do	Depth, 384 feet; just over line on Pennsylvania Coal Co. land; not mined.	351 acres mined. Depth, see sections on Plates 6 and 8; thickness, 3 to 3½ feet; well mined over; pillars generally sound; rooms well filled with gob; conditions fair.

Manville colliery—Operated jointly by the Delaware, Lackawanna & Western and Delaware & Hudson Companies.

(Works Green Ridge section, from the river to the Dunmore line, between Larch and Delaware Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
All beds above the Big vein.		Eroded	Eroded.
Big	No. 21	Worked by Diamond colliery. (See p. 31)	Eroded, except small area on west side of river; worked by Diamond colliery and now caved.
	Nos. 28 and 34	Eroded	
New County	No. 21	Depth, about 160 feet; not mined; workings not extended under school.	16 acres mined. Depth, see sections on Plates 5 and 6; thickness, 5 feet 9 inches; includes 2 feet of refuse; twin bed carries top split 3 to 4 feet thick; separated from main bottom split by 8 to 10 feet of rock; mining only recently begun; chambers, 24 feet; pillars, 36 feet.
	No. 28	Depth, about 100 feet.	
	No. 34	Depth, about 170 feet; not mined.	
Clark	No. 21	Depth, about 261 feet; inaccessible on account of water	315 acres mined. Depth, see sections on Plates 5 and 6; thickness 7 feet, with 6 inches of refuse; old workings; rooms large; pillars well distributed over greater part; considerable chipping of pillars in localities throughout mine; chipping apparently caused more from weight than from air slacking; the southern section of the mine is now caved and closed.
	No. 34	Depth, about 220 feet.	
	No. 28	Depth, 180 feet; workings accessible; openings large; pillars chipped considerably, more on account of weight than air slacking.	
Top Split (here known as Dunmore No. 1).		Not mined	Not mined.
Dunmore No. 1 (here known as No. 2).	No. 21	Depth, about 325 feet; pillars sound and as shown; rooms filled with gob, except roadway.	215 acres mined. Depth, see sections on Plates 5 and 6; thickness, 3½ feet, includes 6 inches of refuse; rooms well gobbed outside of center roadway; conditions fair; no signs of subsidence. The beds known at Manville as No. 1 and 2 Dunmore are really No. 1 Dunmore as known elsewhere, divided into two splits. (See Green Ridge colliery, p. 41.)
	No. 34	Depth, 267 feet; pillars sound and as represented; rooms filled with gob, except roadway.	
Dunmore No. 2 (here known as No. 3).	No. 21	Depth, about 365 feet; pillars sound and well distributed; rooms full of gob, except roadway in center; openings large; conditions fair.	330 acres mined. Depth, see sections on Plates 5 and 6; thickness, 3 feet 3 inches coal; raise 3 to 4 feet of bottom for height; rooms packed with gob, leaving 10 to 12 feet of roadway in center; pillars well distributed, but undersize; no signs of squeeze noted, but squeezed area reported near School No. 28. This bed is elsewhere known as Dunmore No. 2.
	No. 34	Depth, 387 feet; pillars sound and rooms full of gob, except roadway in center.	
	No. 28	Depth, 285 feet; workings inaccessible; reported filled and settled.	
Dunmore No. 3 (here known as No. 4).	No. 21	Depth, 447 feet; pillars sound and according to maps; rooms filled with gob, except roadway; conditions fair.	311 acres mined. Depth, see sections on Plates 5 and 6; thickness 3 feet 8 inches, with 1 inch of refuse; 3 to 4 feet bottom rock lifted and stowed in chambers both sides of 10 or 12 foot roadway; pillars well distributed and sound, but rather small; no weakness noted or reported. This bed is known elsewhere as Dunmore No. 3.
	No. 34	Depth, 376 feet; pillars sound and as represented; rooms filled with gob, excepting roadway; conditions fair.	
	No. 28	Depth, about 345 feet; pillars sound and as shown on maps; rooms filled with gob, except roadway; conditions fair.	

Pennsylvania Coal Co. colliery.

NO. 2 SHAFT COLLIERY.

(Works Petersburg section, between Myrtle Street and Dunmore, east of Taylor Avenue.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Beds above the Clark.		All eroded	1 acre mined. All beds above the Clark are eroded.
Clark	No. 5	Depth, 30 feet; pillars standing firm and sound; no falls; good roof.	20 acres mined. Depth, see sections on Plates 4 and 24; thickness, 5 feet; 1 foot bottom lifted in roads; chambers one-sixth full of gob; old mine; pillars strong; company now reopening, preparing to flush with culm and reclaim pillars.
Dunmore No. 1	do	Depth, 170 feet; pillars strong and well distributed; no signs of weakness; good roof.	105 acres mined. Depth, see sections on Plates 4 and 24; thickness, 4 feet 10 inches clear coal; pillars sound, well distributed, and strong; no signs of weakness; top bench 3½ feet thick, 3 feet above bed; company now remining near outcrop for top coal.
Dunmore No. 2	do	Depth, 200 feet; pillars strong; roof excellent; condition good	73 acres mined. Depth, see sections on Plates 4 and 24; thickness, 5 feet 7 inches; 3 inches of refuse; pillars strong and well distributed; no signs of weakness; pillars near outcrop being reclaimed.
Dunmore No. 3	do	Depth, 250 feet; not mined	16 acres mined. Depth, see sections on Plates 4 and 24; thickness about 3 to 4 feet; not much mined.

Green Ridge Coal Co.

GREEN RIDGE COLLIERY.

(Works small area in city between Ash and Poplar Streets and between Monroe and Taylor Avenues.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark		No schools over these workings	Formerly mined and caved; thickness, 8 feet; now being mined to recover pillars; openings being well filled with gob and surplus rock from lower beds; surface now settling somewhat in parts of this area; depth, about 175 feet. (See sections on Pl. 4.)
Dunmore No. 1		do	Depth, 248 feet (see sections on Pl. 4); thickness, 4 feet; mined, caved, and squeezed years ago; roof resting on old gobs; now being remined to win top coal formerly left; openings long filled, and surplus rock stowed in Clark bed. This upper split of No. 1 Dunmore is known at Manville and Dickson as No. 1, and bottom bench as No. 2 Dunmore.
Dunmore No. 2		No schools over this bed	Depth, 271 feet (see sections on Pl. 4); thickness, about 5 feet; known here as Dunmore No. 3; this bed mined and caved, and inaccessible under city.
Dunmore No. 3, China vein.		do	Mined and caved under city; now inaccessible; depth, 303 feet (see sections on Pl. 4); thickness, 3 to 4 feet.

North End Coal Co. colliery.

NORTH END COLLIERY.

(Works the upper beds near Leggetts Gap.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Beds above Diamond.		Eroded	Eroded.
Diamond	No. 23	do	Company remining old workings; now being worked along outcrop on steep dip and under mountain side, where few improvements exist on surface.
Rock	do	Outcrops under school; pitch, 45°; thickness, 3 to 4 feet; pillars, good size; conditions fair at present, but pillars should not be disturbed.	Company remining old workings (see sections on Pls. 11 and 13); thickness, 3½ feet; divided bed in eastern part; top bench, 3 feet; rock, 3 feet; bottom bench, 3 feet 2 inches; dip of bed about 45°; crop falls liable on surface if upper pillars are removed.
Big	do	Pitch, 45°; bed outcrops about 100 feet north of corner of building; under center of building it is about 135 feet deep to bottom of bed; thickness, 18 feet or more; openings large, and should be filled; south side of school lot now protected by large pillar only partly under school lot; to southward—that is, down pitch from this large pillar—is immense excavation 24 feet high by nearly 90 feet square, only about one-sixth filled with falling rock and coal that has slid off from pillar.	Company remining old workings; thickness, 15 to 25 feet; dip, 45°; openings large; large crop caves liable to occur if pillars are removed.
New County	do	Depth, 275 to 336 feet; pitch, 50°; lowest workings are north of school; thickness, 1½ feet; not mined under school.	Company remining old workings (see sections on Pls. 11 and 13); bed very thin; only mined near outcrop.
Beds below New County.		See Cayuga colliery, page 32	Not mined by North End colliery except in mountain side near outcrop.

Clearview Coal Co. colliery.

(Works South Providence north of Clearview Street, strip 200 feet wide, from North Main Avenue to Keyser Valley Branch of Delaware, Lackawanna & Western Railroad.)

This colliery is now engaged at second mining in the two top beds under above locality. These openings are expected to extend eventually under School No. 40, but will not reach this point for several years. The operation is small, and the output is delivered by wagons.

Bull's Head Coal Co.

(Works near junction of North Main Avenue with Providence Road.)

This colliery is engaged at second mining of the Diamond and the top split of the Four-Foot beds under Winton, Church, and Nassau tracts in above locality. No school improvements on these lands. Operation for local consumption, and delivery by wagon.

Mountain Lake Coal Co.

(Works on mountain side near Mountain Lake, east of Laurel line.)

This mine works an island of coal in Dunmore bed on mountain east of Laurel line, for local consumption; delivery by wagon. No surface improvements over the coal bed.

OBSERVATIONS ON PRESENT MINING CONDITIONS UNDER SCRANTON.

INTRODUCTORY STATEMENT.

As stated in the chapter on the history of anthracite, the mining methods pursued in the earlier days of the industry, not only in Scranton, but everywhere in the anthracite fields, were not conducted with the view of ultimately mining the maximum amount of coal, with the least effect upon the surface, but with a view to immediate profits. Hence, little attention was given to surveying and engineering in the early mines, and great irregularity in the method of mining was the rule rather than the exception. This irregularity makes it exceedingly difficult to columnize pillars now where mining is being done in the solid under worked-over portions of higher coal beds.

To illustrate this particular point.reference is made to the tracings that show the mine workings under the various school properties and are in the possession of the board of school control. These tracings are included in the report made by Messrs. Stevenson and Knight. In the more recent mining under the city, the attempt has been made to remedy this defect, and this attempt has been fairly successful.

As the result of our inspection of the mines under Scranton, as given in detail on preceding pages, we have grouped the mine workings into several classes; in each of these classes approximately similar conditions obtain, and to each the same remedies for sustaining the surface might apply, as stated below:

SURFACE BEDS.

WEST SIDE OF LACKAWANNA RIVER.

On the west side of the Lackawanna River, at the Dodge, Hyde Park, Mt. Pleasant, Diamond, Brisbin, Cayuga, Von Storch, and Leggetts Creek collieries, the surface beds being mined are known as the Eight-foot, Five-foot, and two splits of the Four-foot.

As before stated there is only a small area underlain by the Eight-foot; the areas underlain by the other beds gradually increase in size, as the beds are lower in the measures.

In mining these beds efforts have been made—with a fair degree of success—to columnize the pillars, and about the usual percentage of coal, approximately 33⅓ per cent on first mining, is left in for support of the overburden. In a few places reclamation of pillars, or what is commonly termed "robbing," is in progress, but only where there are comparatively few surface improvements. The menace to the surface from the mining of these beds, as at present conducted, is comparatively slight. When the time comes, however, for the reclamation of pillars from the greater part of the area mentioned, serious surface disturbance may be expected, unless in the meantime some method of support is introduced. Suggestions on this point are given on subsequent pages.

SOUTH AND EAST SIDES OF THE LACKAWANNA RIVER.

On the south and east sides of the Lackawanna River, at the National mine, the Big and the New County beds are nearest the surface under a part of the property, the Clark vein under another part, and the Dunmore No. 2 under still another part. The part underlain by the New County and Big beds carries few improvements and is much caved, so that no serious result is likely to occur by reason of the extraction of the remaining pillars. The mined-over part of the Clark bed, as will be noted from the plans, underlies a larger area than the mined-over part of either of the two overlying beds; and before extraction of pillars from the Clark bed is begun, measures for the support of the overburden should be adopted where the surface improvements are of sufficient value to justify the expense. This observation refers particularly to the part of the bed formerly worked from the old Meadow Brook mine; it underlies a thickly settled portion of the south side.

As will be noted on Plates 19, 20, and 21 the Dunmore No. 2 is the surface bed over a considerable portion of the National and Meadow Brook operations, extending from Beech Street to Sanders Street, and from the Erie & Wyoming Valley Railroad to the Lackawanna River. Examination of workings in this bed, and inspection of the mine maps, indicate that considerably less than the usual one-third has been left in pillars for support. There is no mining now in progress in this bed, nor any extraction of pillars. The pillars observed under the area mentioned (particularly between Beech and Breck Streets), and between Pittston Avenue and Crown Avenue, show signs of pressure and should not be disturbed. Although it is true that these pillars have stood without serious subsidence for many years, there is a possibility of a "creep" or "squeeze," such as would unquestionably cause surface damage in the area just mentioned, starting at almost any time. Remedial measures should be applied in the Dunmore No. 2 bed in this area at the earliest possible moment, before a creep or squeeze starts, as the conditions are such that if once started, no remedies that might be attempted, and hastily applied, would be effective in preventing a general subsidence of practically all the above mentioned area.

CENTRAL PART OF SCRANTON.

The Pine Brook colliery of the Scranton Coal Co. includes a large area in the central part of the city of Scranton, as will be noted from Plates Nos. 1, 2, 3, 4, 5, and 22. This area extends eastward from Beech Street on the south side to Poplar Street at the Dunmore line, and from the Lackawanna River to the outcrop of the Dunmore beds near Nay Aug Park.

Under a portion of the territory mentioned, the Big or Fourteen-foot bed is present. It was partly worked over many years ago by the old Lackawanna Iron & Coal Co. The area underlain by this bed is what is generally known as Sanderson Hill, and is clearly shown in Plates Nos. 2, 3, and 4. The old workings in the Big bed are inaccessible, except a very small portion that extends from the Pine Brook Traveling Way to a point under the Central High School. Although there may be other openings to the workings in this bed, they are unknown to us. From information furnished by various persons, it is believed that the old maps of the workings in this bed are reasonably accurate.

The part of these workings that was inspected showed the pillars in good condition and the roof over the openings fairly sound, although local falls have occurred in many openings preventing access to points beyond. According to our information no serious "creeps" or "squeezes" have occurred in this bed, and unless some disturbance takes place through subsidence of the measures below it not much danger is to be apprehended from a general creep in this bed. We are, however, of the opinion that detailed investigations should be made by reopening small holes through the local falls mentioned above, and by sinking shallow shafts at various points for the purpose of making accurate surveys of the mine workings. These should be maintained as avenues through which to conduct or transport material for filling. It is deemed especially important that these openings be completely filled, on account of the nearness of this bed to the surface, and the value of the surface improvements. Methods of protection will be described in another chapter.

Below the Big bed the next bed that has been worked from the Pine Brook shaft is the Clark. The New County bed has not been worked at Pine Brook, but it is present and will doubtless be mined in the future. The Pine Brook workings include what was formerly the property of the Fair Lawn Coal Co., between Gibson and Ash Streets, and Capouse and Quincy Avenues. The usual rule of leaving approximately one-third of the coal was generally followed in the major part of the workings from the Pine Brook shaft, but much less than one-third was left in the Clark bed where worked from Fair Lawn. This bed is from 8 to 11 feet thick; a bench of coal at about the middle of the bed that is considerably softer than the balance was noted. This bench is affected by what is known as "air slack," causing it to chip and flake off, and to show the first signs of any undue pressure on the pillars.

A very large proportion of the pillars inspected an this bed show unmistakable signs of pressure, particularly in the Fair Lawn workings and outwardly from this area for a considerable distance. These signs of pressure on the pillars can not, in our opinion, be solely attributed to air slack, but are, we believe, the first stage of a creep or squeeze that if fully started may result in the complete collapse of the pillars in a large part of the area mentioned; it would bring down the roof, and unquestionably affect the surface. These indications, as before stated, are most serious in the Fair Lawn workings; they are observed on both sides of the tract and under the portion of the property where the Big Vein is present. Should a general squeeze take place in the Clark bed workings it would certainly affect the pillars and overlying strata of the Big bed and result in a very serious disturbance of the surface.

We deem it important to lay particular stress on the necessity for promptly taking measures to prevent the *starting* of a general squeeze or creep in the Clark bed at the Pine Brook colliery; for such a squeeze might cause breakages of gas, water and sewer mains, and resultant damages.

A point of particular weakness in this bed is under the Technical High School, near the intersection of Adams Avenue and Gibson Street. We have been informed that the Scranton Coal Co. has begun flushing culm into the workings under this important building, and that it is their intention to fill these workings as rapidly as possible. When this flushing is completed and a block of 1 or 2 acres is completely flushed, it will strengthen not only the point immediately filled, but have a tendency to support the roof for some distance on all sides of the artificial pillar thus introduced.

The old Lackawanna Iron & Coal Co. opened and worked the Clark bed by a drift from Roaring Brook gorge, near the Laurel line station. These old workings are now inaccessible, but maps inspected show an area worked over on the north and east sides of the river bank between the Delaware, Lackawanna & Western Railroad and Vine Street, and Madison and Clay Avenues. The maps show that very small pillars were left in. The old workings should be opened and artificial pillars made by flushing. The same plan is suggested for the Big, or Fourteen-foot, bed under Sanderson Hill, and for the old Iron Co. workings in this bed on the south side of Roaring Brook, under Spruk's lumber yard and vicinity.

At the Manville colliery, operated jointly by the Delaware, Lackawanna & Western and the Delaware & Hudson Companies, the surface bed is the New County. This bed has been attacked recently, and is now being mined under the Green Ridge section of the city. It averages about 6 feet thick, with nearly 2 feet of refuse in several benches. We were informed that under the old leases the lessees were prohibited from mining this bed, but by a recent modification of the terms of certain of the leases they are permitted to extract one-third of the bed, leaving two-thirds as pillars to support the overburden. Considering the depth at which the bed lies and the character of the overlying strata, we do not think there is much danger to the surface from mining this bed, if not more than one-third of the coal is extracted.

At this colliery the Clark bed has been worked over the whole of the area tributary to the mine, as will be noted from Plates 5, 6, and 7, and is at present abandoned, no solid or pillar mining being in progress. About the usual one-third of the coal has been left to support the roof. Many parts of these workings are inaccessible because of local falls, and a small part of the workings has been filled with culm, principally under surface improvements controlled by the mining company.

The pillars in this bed show the usual chipping, due to air slack, and in some places signs of squeeze or creep, particularly in the vicinity of Poplar Street and between Capouse and Washington Avenues. The boundary pillar between the Manville workings and those of the Pine Brook mine is very small, and would not be of sufficient strength, in our opinion, to break off or stop a squeeze that might originate on either side of it. We are of the opinion, therefore, that filling or other remedial measures for the support of the overburden should be started in portions of the Manville Clark-bed workings, as we recommended at Pine Brook.

At the Dickson mine of the Delaware & Hudson Co. the surface bed is the Big, or Fourteen-foot, which is 10 to 14 feet thick. This bed was worked some years ago between the river and Dickson Avenue and between Delaware and Market Streets; a very small part east of Sanderson Avenue was also worked.

No mining, either of solid coal or pillars is now being done in this bed. There is, however, a considerable block of solid coal east of Sanderson Avenue that may at some time be extracted. If mining is resumed in this bed it should be conducted with great care, as the bed is close to the surface, and the overlying strata are weak.

Parts of this bed west of the Delaware & Hudson Railroad and under the Lackawanna River have been flushed with culm, and the balance of the workings should be filled in the same manner. The possibility of recovering the pillars in the worked-over part of this bed without serious damage to the surface is, in our opinion, decidedly doubtful, even though the openings may be completely filled with culm or other flushed-in material.

The New County bed has not been worked at the Dickson mine, being considered too thin and impure for profitable extraction. This bed, however, may be mined hereafter.

The Clark bed has been mined in about the same manner as at Pine Brook and Manville, and the same remarks regarding conditions apply. Portions of this bed also have been filled with culm, particularly toward the Lackawanna River.

MIDDLE BEDS.

HYDE PARK AND PROVIDENCE SECTIONS.

As before mentioned, under Hyde Park and Providence, the middle series of beds, the Diamond, Rock, Big, New County, and Clark (especially the first three of these), are quite thick and the intervening strata are comparatively thin and weak. On account of the failure in the past to columnize pillars, the workings in these beds, where now open, constitute a serious menace to the surface, and this portion of the city will be the most expensive and difficult to protect. However, it should be noted that very large areas of the three uppermost beds have been closed by crushing of the pillars and strata in the past. This condition was observed in parts of the Bellevue, Hyde Park, Hampton, Oxford, Mount Pleasant, Diamond, Brisbin, Cayuga, Von Storch, Leggetts Creek, and Marvine mines. Where such complete crushing of the pillars, with consequent subsidence of the overlying strata and surface, has taken place in the past, no serious apprehensions need be entertained of future damage to the surface improvements, unless, in the process of mining lower veins, insufficient pillar support is left to carry the overburden and a creep or squeeze takes place. This has been the case recently at the Leggetts Creek mine in mining the lower Dunmore bed at a depth of 700 feet, where was applied the usual though here insufficient rule of leaving about one-third of the coal for support.

Where the workings in these thick and closely lying beds are not closed by a general crush (and no one knows how large or extensive such openings may be) there is always a liability to a repetition of the same kind of subsidence as that which wrecked No. 16 School. In this connection attention is particularly called to the conditions existing under No. 12 School. Here the Diamond bed is very near the surface, within 13 to 40 feet. Second mining is now in progress to win bottom coal formerly left in this bed, and the New County bed is being mined. An attempt is being made to drive openings in the New County bed under openings in the Big bed, but this attempt is not altogether successful. These conditions, we believe, are quite similar to those formerly existing under No. 16 School.

We strongly recommend that the pillars in the Diamond, Rock, Big, and New County beds under this building should not be disturbed, and that the openings in the Diamond, Rock, and Big beds should be filled as promptly as possible. Such filling could easily be done by drilling one or two bore holes in the school lot. The filling of openings should not be confined to the school lot only, but should extend outside the lot some distance, as there is danger in case of a cave in any seam, of the side pull damaging the building.

It is also deemed important to refer particularly to No. 23 School, where the Rock and the Big bed pillars now in place should not under any circumstances be disturbed, neither under the school lot nor for some distance outside of it, as shown by the maps formerly submitted to the school board by the North End Coal Co. We also suggest that the openings under this school property should be flushed full of sand, culm, or other material.

The best manner of applying an effective remedy for this serious menace is difficult to determine, because the openings are so large, on account of the thickness of the seams, and there is the difficulty of procuring the material for this purpose.

DUNMORE BEDS.

The deeper-lying Dunmore beds under the major portion of the city, constitute a class by themselves. They are in many places so thin that during mining much top or bottom rock has been removed in all the gangways and along roads in the chambers to make room for cars and mules. This rock with the large quantity of interstratified refuse that is usually present in the coal beds nearly fills the mined-out space when stowed in the chambers, and thus constitutes a check to quick or total subsidence. Then, too, the thickness of the rock over the coal is generally so great that local caves in the workings are not likely to affect the surface. The greatest menace to the surface property from these deep thin beds is through a general subsidence—a creep or squeeze extending over large areas. Even then the settlement will be gradual, and as a rule so uniform as to cause little or no damage to surface property, except where the uniformity of the subsidence is interrupted or prevented by the presence of very large pillars or solid blocks of unmined coal, in which event, buildings located on the surface over or near the margin of such large pillars will be liable to considerable damage by the side pull, or uneven subsidence.

In consequence of these facts we would advise as a measure of preventing damage to surface improvements over these deeper beds that the Dunmore beds be mined in the usual manner under large blocks of coal now held as reservations in any of the coal beds overlying the Dunmore and not at present mined nor intended to be mined.

RECAPITULATION.

Thus, to recapitulate, we have three general sets of conditions which naturally divide the coal workings into as many separate classes, to wit:

1. The surface beds, viz, on the west side, the Eight-foot, Five-foot, and Four-foot; on the east side, the Big, New County, Clark, and Dunmore No. 2, of which the latter are surface beds under different parts of the south side and central city sections.

2. The middle series of beds, viz, Diamond, Rock, Big, New County, and Clark, under the Hyde Park and Providence sections.
3. The three lowest beds, Dunmore No. 1, Dunmore No. 2, and Dunmore No. 3, under the major part of the city.

METHODS FOR SURFACE SUPPORT.

The methods employed at the present time for supporting the surface over the coal mines under the city of Scranton are of two general classes, which may be termed natural and artificial.

NATURAL OR PILLAR SUPPORT.

The natural method, of course, consists in leaving pillars of coal sufficiently strong to support the weight of the earth and rock that overlie the coal bed. The efficiency and value of these supports depend upon their size. That is, the horizontal area, the height of the pillar (which is fixed by the thickness of the coal bed), the compressive strength of the coal, the regularity of distribution of the pillars, and whether or not they are columnized with respect to pillars in near-by overlying or underlying beds, all have to be considered. In this vicinity the size of pillars has been mainly regulated by the one-third rule previously mentioned.

ARTIFICIAL SUPPORT.

FLUSHING.

There are several artificial methods of roof support, the principal and most effective of which is known as the flushing method. In this method coal culm and other fine refuse is washed into the mines through pipes by means of a stream of water, thus filling the desired portions of the mine.

This method was first used at Shenandoah, Pa., by the Philadelphia & Reading Coal & Iron Co. Afterwards it was introduced at Plymouth, Pa., and now has been adopted and is in practice over the whole anthracite region. Only culm is used, and the method has been adopted mainly for the purpose of protecting those parts of the mine or of the surface which it is necessary to support in order to maintain the mining operations.

Under Scranton considerable flushing has been done at various places, as indicated in the chapter on "Present mining conditions." Foreign engineers, after inspecting the process in this country, have adopted it in Europe. There, much extended and amplified, it is now an essential part of the more recent mining methods by which the engineers are able to recover all the coal; the excavated spaces are filled by the flushing method with crushed rock, sand, gravel, and soil obtained from quarries opened for the purpose, and also with ashes and city refuse, some of which is transported long distances over the surface to the flush pipes. Foreign engineers find that when they thus remove all the coal, a gradual though small surface settlement results, the amount of which depends upon the depth and the thickness of the coal. In this country, however, we can not hope to profitably use such expensive mining methods as may obtain abroad, because the cost of labor in the United States is very much greater and the market price of coal very much less than in Europe. The appearance of culm flushing is shown by Plate 26.

COGS.

It is frequently necessary in the course of mining to make use of some roof-supporting device that may be quickly constructed and is withal possessed of great strength. The timber crib filled with mine rock—known in mining parlance as a "cog"—has been found to answer these conditions in a very satisfactory manner, and is extensively used in all coal-mining districts. The cog consists simply of a rough crib of stout logs placed one above the other, log-house fashion, the spaces between the logs being chinked and the interior being filled with rock from the mine. (See Pl. 27 *A*.) This construction is quickly erected, and possesses great strength. Of course it is not permanent because the timbers decay in a few years. Cogs are mainly used for the purpose of stopping a settlement, squeeze or creep which the mine foreman knows to be imminent or in progress. A view of a squeezed area in the Dunmore bed is shown in Plate 29 *A*. When sufficient cogs are placed in proper localities the strata above the bed will frequently crack through to the surface, and the progress of the squeeze or creep will thus be stopped.

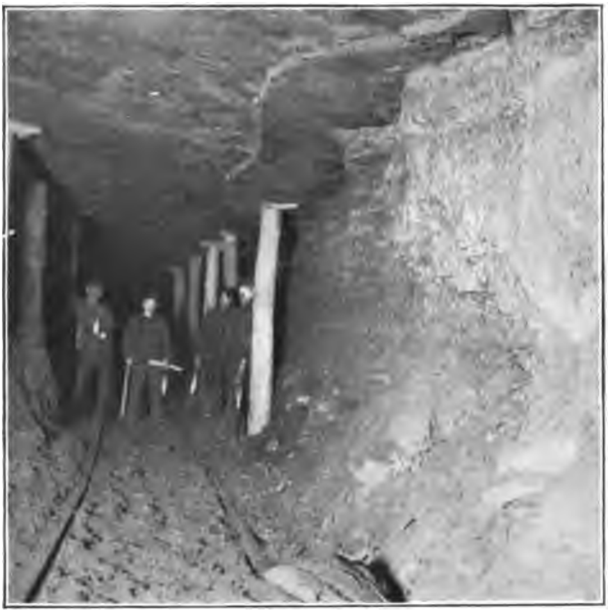
GOB PIERS.

Gob piers are pillars built of such refuse rock as may be readily found in most mines—mainly bony coal, fire clay, and slate. Such rock is mostly soft and does not possess very great compressive strength. Some of these piers have a square outer or inclosing wall, and are filled with mine refuse shoveled into them. In others the interior is laid up by hand and the rocks are more carefully compacted by filling the voids with fine mine refuse.

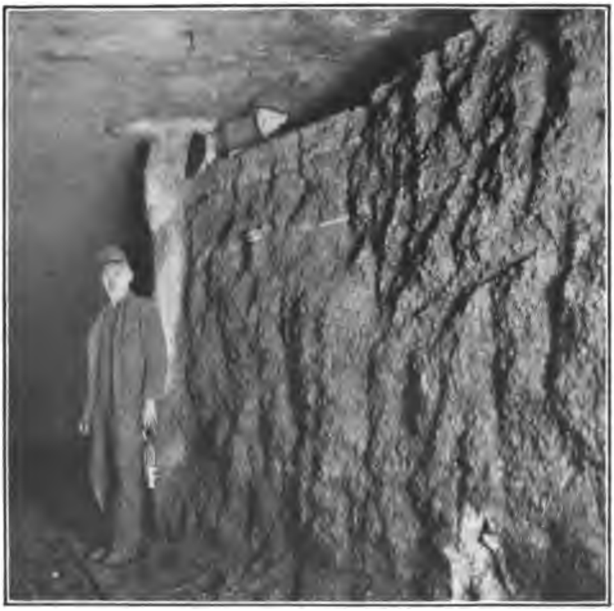
A great many such piers have been built under localities in the city of Scranton for the purpose of supporting the roof under valuable surface improvements. (See Pls. 27 *B* and 28.) The value of such piers, that is, their supporting strength, depends upon the compressive strength of the materials of which they are constructed. The value will be greater if the voids between the larger pieces are filled with the small rock and shoveled material from the mine.

GOB STOWAGE IN ROOMS.

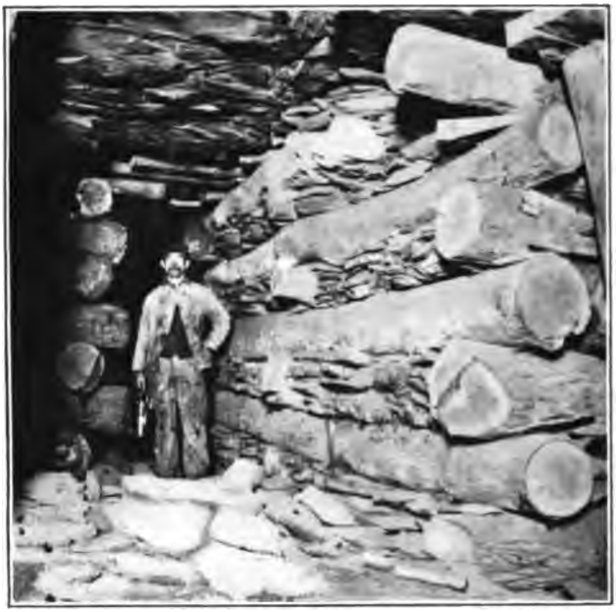
Most coal beds consist of interstratified layers of coal, fire clay, slate, and bony coal; the three latter, of course, compose the prin-



A. GANGWAY CUT THROUGH CULM FLUSHING, OXFORD MINE.



B. GANGWAY CUT THROUGH FLUSHING, CULM STANDING AS A VERTICAL SELF-SUSTAINING WALL, OXFORD MINE.



A. TIMBER AND ROCK COG, IN BELLEVUE MINE.

B. GOB PIER IN DUNMORE NO. 2 BED, NATIONAL MINE.

cipal refuse material of the mine. In all the mining methods adopted under the city of Scranton, all the material of the coal beds that is not coal is laid aside as refuse and stowed away in the chambers, either on one side or on both sides of the mine tracks. In thin beds where it is necessary to remove some of the roof rock or take up some of the floor of the mine in order to obtain height sufficient for the mules and the men to travel along the roads, much mine refuse is produced, which is also stowed in the chambers. In beds less than 4 feet thick many chambers are filled with mine refuse or gob, as it is more familiarly termed, from floor to roof. In places this gob is merely thrown in carelessly, or is shoveled in; in other localities it is packed as tightly as possible by hand. It frequently happens that the whole chamber from pillar to pillar is packed full of mine refuse. Where there is much interstratified fire clay or bone in the coal bed there will be larger quantities of the gob, and the thinner the bed the greater will be the quantity of mine rock raised or taken down for roads. Consequently, this stowage of gob in the rooms of the mines under the city of Scranton becomes an important item when the support of the surface over these coal beds is considered. As in the case of the gob piers and the cogs, the supporting value of stowed gob depends upon the compressibility of the material of which it is composed.

CONCRETE AND MASONRY PIERS.

The above methods of artificial support already mentioned are comparatively cheap to install. Some other methods of support used in the city of Scranton are concrete and sandstone piers. In these the material for construction has been introduced from the surface (through bore holes in the case of concrete or through shafts from the surface in the case of blocks of sandstone), and in the mine has been wrought into substantial piers by the use of cement. (See Pl. 29 *B*.) Though these forms of piers are much more substantial than those previously mentioned, they are also much more costly; consequently fewer of them have been installed.

IRON PROPS.

In one place, namely, in the Big bed under the Central High School building in this city, a number of iron props or posts have been installed as additional roof support. There has been no subsidence of pillars in the locality where they have been used; therefore the supporting value of the props has not been tested and their efficiency is largely a matter of opinion. In any case they are costly to install, and it is entirely probable that much more efficient means might be used for the same purpose at less expenditure.

TESTS OF ROOF-SUPPORTING DEVICES.

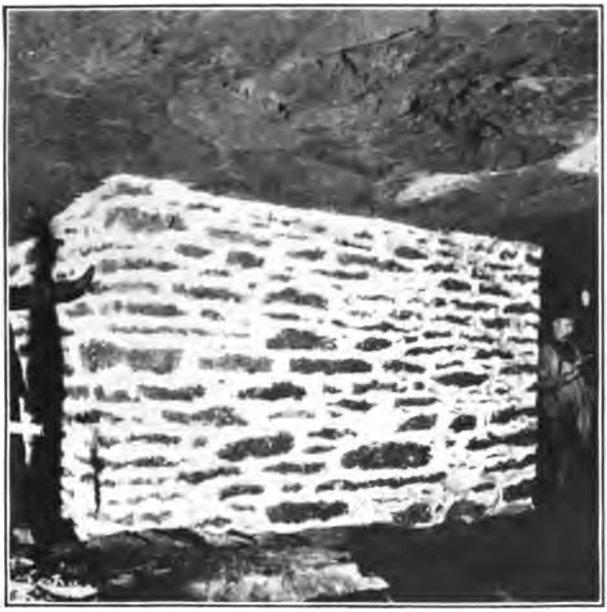
COMPRESSIVE STRENGTH OF ANTHRACITE.

In 1903 an exhaustive series of tests was conducted under the direction of a committee of the Scranton Engineers' Club for the purpose of determining the compressive strength of anthracite coal. The report of this committee on tests is printed in an appendix (see p. 77) to this report. The results, however, may be summed up briefly in the statement that a pressure of 216 tons per square foot will cause the average ordinary mine pillar to begin cracking, and a pressure about twice as great (432 tons per square foot) will crush it to powder.

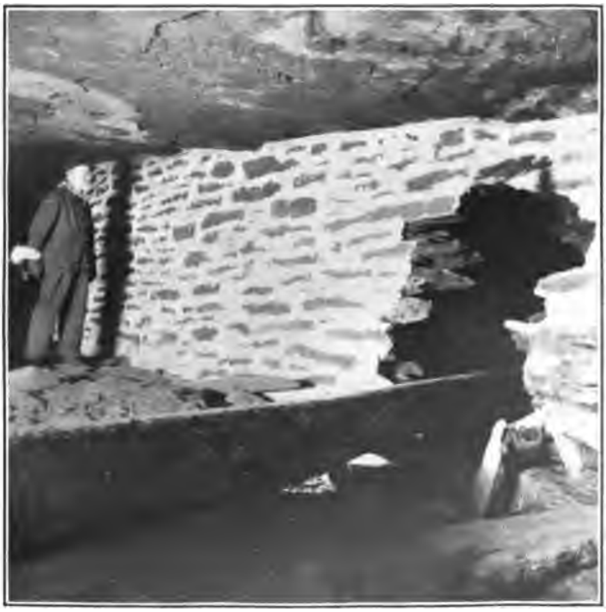
This general statement, however, does not apply equally to all coal beds, for the tests prove a great variation in strength, even between different parts of the same bed. In some instances the weight required to crack the pillars was as low as 30 tons per square foot.

TESTS AT LEHIGH UNIVERSITY.

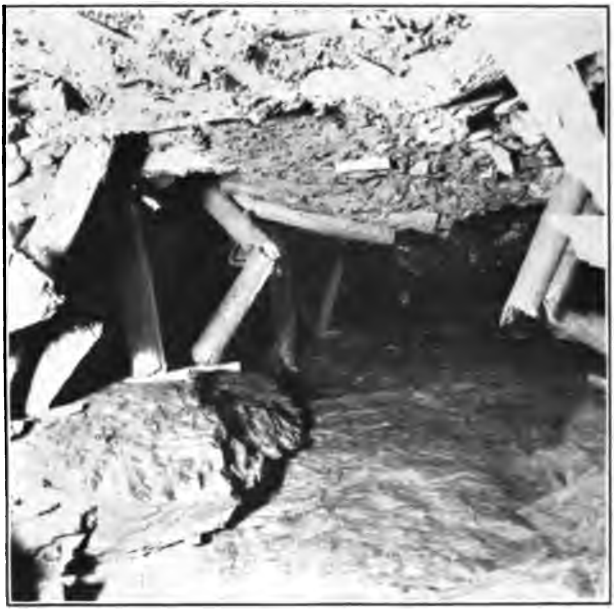
In order to test the value of the several artificial devices for supporting the roof of a coal mine, as well as to search out an inexpensive combination of materials which might be more cheaply installed and withal more permanent and efficient, and better adapted to certain localities than some of those mentioned, we prosecuted a series of tests at the Fritz engineering laboratory at Lehigh University, South Bethlehem, Pa., the results of which are also given in an appendix (see p. 83) to this report. A tabulated summary of the results follows, and from it mining engineers may readily compute the supporting value of any particular construction.



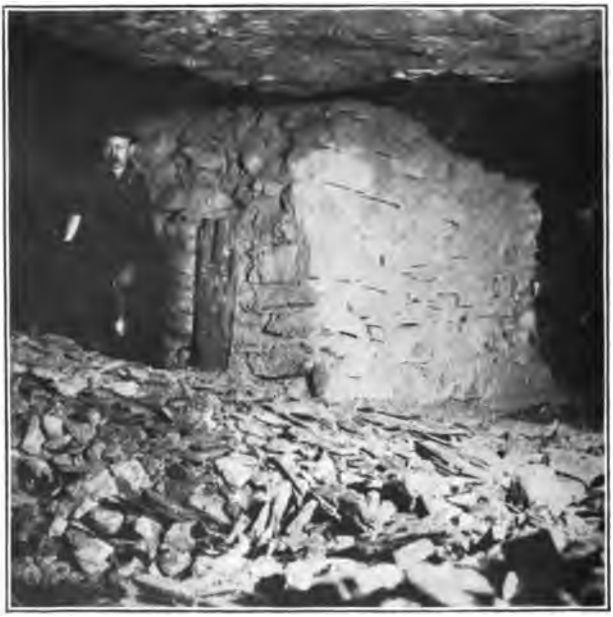
A. A GOB PIER IN CLARK BED UNDER CENTRAL HIGH SCHOOL BUILDING, PINE BROOK MINE.



B. SIMILAR PIER WITH FLUSH PIPE PASSING THROUGH SHOWS SUPERFICIAL CHARACTER OF MORTAR POINTING.



A. VIEW IN SQUEEZED AREA IN DUNMORE BED, LEGETTS CREEK MINE.



B. SANDSTONE AND CEMENT MASONRY PIER IN DUNMORE NO. 2 BED UNDER SCHOOL NO. 15, NATIONAL MINE.

TABLE 3.—*Results of tests of compressive strength of various forms of roof support.*

No. of test.	Construction tested.	Net tons per square foot required to produce compression of—						Compression and load (tons per square foot) at end of test.	Remarks.
		1 per cent.	3 per cent.	5 per cent.	10 per cent.	20 per cent.	30 per cent.		
1	Rectangular piers of mine rock		0.8	1.4	2.7	9.5	23		Average construction; voids not filled.
2	Circular pier of mine rock		3.5	5.67	11	22	38.5	Compression, 31 per cent; load, 42.5.	Well constructed; voids filled with small and shovel stuff.
3	Timber crib filled with mine rock		.6	1.37	5.11	20.3	31.5		Average construction.
4	Pile of broken sandstone; small pieces				4	9.3	22.4	Compression, 46 per cent; load, 104.5.	In these tests the material was not confined, but was free to expand laterally. (See appendix, pp. 84–86.)
5	Pile of small-size broken sandstone and sand.			1.6	4	13.5	35	Compression, 45 per cent; load, 144.	
6	Pile of broken sandstone; large pieces		3.6	5	9.1	26.4	37	Compression, 41 per cent; load, 75.	
7	Pile of coal-measures sandstone similar to No. 6.	0.8	2.1	3.5	9	33.4		Compression, 27 per cent; load, 56.	
8	Pile of river sand							Compression, 63 per cent; load, 108.	
9	Broken sandstone in cylinder		3.33	5.55	13.32	46.6	98.6	Compression, 35 per cent; load, 666.	In these tests the material was confined and could not expand laterally. (See appendix, pp. 86–88.)
10	Broken sandstone and sand in cylinder		3.5	5.77	24.42	308.5		Compression, 23 per cent; load, 686.	
11	Dry coal ashes in cylinder Coal ashes flushed in with water		1	1.86	5.32	10.8 5.50	25 22	Compression, 51 per cent; load, 666.	
12	Wet culm flushed in cylinder; partly dried (average of two tests).	2.44	8.9	14.28	35.52	138.7	444	Compression, 33 per cent; load, 668.	
13	Dry sand in cylinder	.88	3	5.27	33.3	129	499	Compression, 32.2 per cent; load, 666.	
14	Wet sand flushed in and partly dried	8.4	39.3	67	173.8	555.4		Compression, 20.75 per cent; load, 666.	
15	Concrete made of cement, sand, and gravel; 4 months old; 1 barrel Portland cement to each cubic yard of concrete (about one part cement to seven parts sand and gravel); piers 3 inches by 2.81 inches by 3.85 inches high.	9	84 Cracked.	Gradually crushed to pieces under continuous load of 45 tons.					This test was made at the Dickson Works of the Allis-Chalmers Co. in Scranton, by William Griffith.

DRY FILLING.

Although we recognize that the flushing process is the most substantial method for artificially supporting the roof of coal mines, and that it is also universally suitable for thin or thick beds and deep or shallow beds, nevertheless the method is not always applicable or convenient. There are many localities in the coal mines where it may be either preferable or permissible to resort to some of the other less efficient or less costly methods of roof support, which for one reason or another are more adaptable to a particular locality. Therefore we refer to the improvements that may be made in the different methods of dry filling.

IMPROVED METHODS OF GOB STOWAGE.

Formerly the gob of coal mines was disposed indiscriminately over the chamber at the side of the roadway, mainly for the purpose of getting rid of it at as little cost as possible. A casual inspection of the comparative table of tests on page 55 will show that well-constructed gob piers are much stronger than those indifferently built. It is also evident that in supporting the roof of coal mines, as well as in other matters, "an ounce of prevention is worth a pound of cure." The effort, therefore, should be to prevent the first small settlement, and the way in which to accomplish this effort as far as possible in the matter of stowage will be to pack the rock fragments carefully and tightly against the sides of the pillars from floor to roof, irrespective of the horizontal area occupied, and to use the fine refuse, so far as may be, to fill the voids. If the gob now contained in the thinner seams under the city of Scranton had been carefully packed so as to completely fill the space from floor to roof it would not only reinforce and preserve the strength of the coal pillars, but would present very much greater resistance to pressure and would be a much more efficient roof support than is afforded by the usual present stowage with 1 to 2 feet of space between the top of the stowed gob and the mine roof.

In some beds now working there is a surplus of mine rock which can not be stowed in the chambers and must be hauled out into other parts of the mines. If it is determined to continue thus to stow this material instead of hauling it to the surface and grinding it for flushing purposes, as has been previously mentioned (see p. 55), the purpose of roof support would be better served if the places for depositing this surplus stowage were selected with reference to the weak parts of the mines, or with reference to the support of the ground under some particularly valuable surface improvement.

Commendable work is being done along this line at the Cayuga mine of the Delaware, Lackawanna & Western Railroad; the pillars are being extracted in a surface bed and the space formerly occupied both by the chambers and the pillars is being completely filled with surplus rock taken from a lower bed.

BLASTING ROOF AND FLOOR IN THINNER BEDS.

It is a well-known fact that loose rock occupies one and two-thirds to two times the volume of the same weight of solid rock. In other words, if a cubic yard of solid rock be broken to pieces the pieces will occupy a space of 1⅔ to 2 cubic yards.

We have conceived the idea of taking advantage of this fact for the purpose of cheaply producing an adequate roof support for certain classes of coal beds under the city. So far as we know, this method, in its entirety, has never been used before in any coal-mining district, and the suggestion is here made for the first time.

The process would be applicable to beds less than 6 feet thick and so situated that the shock of heavy blasting would not produce ruptures of the measures supporting adjacent coal beds. It consists simply in blowing up the floor of the mine to a depth equal to the thickness of the bed, and blowing down the roof of the mine directly over, to a height equal to the thickness of the bed. This would produce a total thickness of loose rock equal to three times the thickness of the coal bed. The rock would be well packed together and have great supporting power, and the process would be comparatively inexpensive.

This method might be adopted throughout the Dunmore and other thin seams, by blasting down the roof and raising the floor in the abandoned rooms or the roadways between the gob piles in the chambers. Wherever it is applied the effort should be to completely fill the whole width of the chamber or roadway from pillar to pillar, so that the loose rock will be confined between the pillars, thus greatly increasing its resistance to compression. The value and supporting power of this method of roof support and of other methods will be referred to below.

GOB PIERS AND TIMBER COGS.

There are localities under the city of Scranton where it has been deemed advisable in the past to build gob piers for the support of the roof overlying certain surface beds. The Lehigh University tests mentioned in this report show that this method of support lacks the merit of strength. The piers are very compressible, and as they have been built heretofore their supporting value is small. Their efficiency would be greatly increased, as shown by the differences between test No. 1 and No. 2 (pp. 83–84), by building them in circular form and carefully filling all the voids between the larger pieces with smaller particles of shovel stuff.

CONCRETE PIERS.

During the progress of this investigation many persons have called our attention to concrete piers as suitable for firm roof supports. This material is so costly, however, that we have hesitated to recommend it except perhaps in special cases where very valuable surface property requires unyielding support and the expense of such support is no object.

We have tested the strength of one sample of concrete composed of about the cheapest good materials available for this locality, i. e., cement, sand, and gravel. The results of this test are shown in Table 3, test 15, and Table 4, test 14 (pp. 55, 59). It will be noted that such concrete is firm and comparatively unyielding up to a certain maximum strength sufficient to cause about 3 per cent of compression and cracking, beyond which a much less weight will crush it to powder. This latter characteristic is an exceptionally bad one for a mine roof support, because such piers are liable, under the excessive stress due to a general squeeze, to collapse quickly, and thus permit the sort of caving that resembles a small though severe local earthquake in its suddenness and excessively damaging effect on the surface improvements.

DRY FILLING WITH BROKEN STONE OR SAND.

For the construction of isolated and more substantial low-cost piers in the surface beds under the city, to take the place of the gob piers for the purpose of the local support of valuable surface improvements where general flushing is not convenient, we strongly recommend the filling with broken stone or sand, or a combination of these materials, through bore holes from the surface.

Filling of this sort should be spread out by hand in the inside of the mine so that it completely fills the whole width of the space from pillar to pillar, and thus, being more or less confined has its supporting power increased. If broken stone is used the relative proportion of the voids should be ascertained and an amount of sand, coal ashes, or other fine material added sufficient to fill these voids.

By this method one bore hole 4 to 6 inches in diameter would be necessary for each pier, and inasmuch as these materials, if flushed in by water, are much more closely packed and have from ten to fifteen times the compressive strength of dry filling, it would always be wise, if water is handy or is not too costly, to flush the material in, using in some cases the city water, or the water from the gutters during the storm seasons for the purpose. The more sand there is in the mixture the better it will be, for our tests have shown that clear river sand is the strongest and least yielding material available, if it is flushed into and confined in the limits of a mine chamber; moreover it is about the cheapest material obtainable for this purpose in Scranton.

THE VALUE OF THE DEVICES FOR ROOF SUPPORT.

The following table sets forth the value of the above devices for dry filling, and also the value of the different materials that are available for flushing coal mines in this locality. The values are directly deduced from the results of the tests made by us at Lehigh University, and we think are sufficiently clear to be self-explanatory. We might add, however, that test 1 would represent the ordinary supporting value of gob piers or gob pillars. Test 2 represents the value of well-constructed gob piers, while tests 6, 7, and 8 set forth the supporting value of mine rooms filled with rock blasted from the floor and roof, as heretofore mentioned; and tests 12 and 13 indicate the supporting strength of fine materials, such as coal culm and river sand, if flushed in with water. At the bottom a comparison is made between the supporting value of the flushed culm and the flushed sand, and the concrete piers of the same nature as the sample tested.

TABLE 4.—*Supporting strength of various forms of dry filling.*

Kind of material comprising the artificial supports.	Approximate depth, in feet, of column of coal measure rock 1 foot square, necessary to compress artificial roof supports—						Remarks.
Per cent of compression	1	3	5	10	20	30	
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
1. Rectangular gob piers, ordinary construction	......	10	12	36	125	306	Free to expand laterally.
2. Circular piers of mine rock well constructed	......	46	75	146	292	512	
3. Timber cogs filled with gob, average construction	......	8	68	182	270	419	
4. Loose pile of broken sandstone through 1¾-inch ring, 40 per cent voids	......	....	20	53	124	298	
5. Pile broken sandstone, 40 per cent voids, voids filled with sand	......	....	21	53	186	465	
6. Loose pile large size broken sand rock, 45 per cent voids	......	48	66	121	351	492	
7. Mine room filled with large broken sand rock, 50 per cent voids	12	27	45	117	434	[a] 615	
8. Mine room filled with broken sandstone, 40 per cent voids	......	44	74	177	619	1,310	
9. Mine room filled with broken sandstone, 40 per cent voids filled with sand	......	46	77	325	6,000	[b] 8,860	
10. Mine chamber filled with dry coal ashes, 64 per cent voids	......	13	25	70	143	332	
11. Mine room filled with dry river sand	12	40	70	442	1,715	6,640	
12. Mine room filled with river sand flushed in with water	111	522	891	2,310	....	[c] 8,860	
13. Mine chamber filled with coal culm flushed in with water	32	118	190	472	1,822	5,905	
14. Concrete pier, 1 part cement, 7 parts sand and gravel; 5 months old	117	1,092	Gradually cracked to pieces under continuous load equal to 600 feet of rock.				
Resistance of flushed culm	1	1	1	1	1	....	Comparative.
Resistance of flushed sand	3.5	4.4	4.7	5	4	....	
Concrete pier	3.6	9	(d)	(d)	(d)	(d)	

[a] 27 per cent settlement.
[b] 23 per cent settlement.
[c] 20¾ per cent settlement.
[d] Worthless.

SUGGESTIONS FOR IMPROVEMENT IN MINING METHODS AND PILLAR SUPPORT.

The solid coal remaining to be mined under the city of Scranton is mainly in the Dunmore beds Nos. 1, 2, and 3. These beds are from 200 to 600 feet below the surface under the greater portion of the city.

Future mining plans, we think, should provide for leaving at least 50 per cent of the coal in these beds on first mining, and the columnization of the pillars throughout all new mining as far as possible.

FLUSHING.

Reference has been made to the practice, now quite general, of flushing culm into the mines. This is being done at nearly all of the collieries within the city limits, and the method and effectiveness of this kind of support was observed by personal inspection underground (see Pl. 26).

With reference to the tests made at Lehigh University of the compressibility of the several kinds of support now in use or suggested, we are of the opinion that a practicable method for the support of the overburden, utility and cost being considered, is flushing the openings with culm, ashes, sand, broken stone, material excavated from cellars, and other stuff of similar nature that can be reduced to a size small enough to be carried in pipes with water.

As before referred to, the flushing of mines for the support of the overburden has been adopted in Europe with marked success, both in the matter of support and recovery of all the mineral, the material used for filling being sand, loam, crushed slag, and crushed stone.

It is manifest that the quantity of culm available for flushing the extensive mine openings is insufficient, even if all of that now on the surface within the city limits, together with that produced in the preparation of the present output of coal were put into the mines.

According to figures we have assembled and supplemented with estimates, it appears that there has been extracted from the beds underlying the city, approximately 221,000,000 tons of coal and other material.

The workings under the city are, of course, not all open, large areas having been closed by general caves and squeezes. It is not possible to determine the proportion of openings that have been thus closed or filled, but a conservative estimate of the space now open would be that it probably does not exceed 50 per cent of the original.

The positive protection of all of the surface would appear to require the filling with some supporting material of all of the open spaces as rapidly as the coal is extracted; but such a scheme is, of course, impracticable. It therefore remains to determine about what proportion of the openings to be flushed would afford reasonable protection. To determine this point definitely would necessitate a much more thorough investigation and more detailed surveys than were contemplated in the general investigation upon which we are now engaged. We would, however, express the opinion that conditions could be materially improved by the insertion of artificial pillars reinforcing the natural pillars of coal in blocks of from 1 to 5 acres at points where the danger of subsidence appears greatest; such artificial pillars to be arranged with some degree of regularity, so that the overlying strata between the artificial pillar supports would act as natural bridges. This suggestion is made in order to distribute the relief measures over as large an area as possible, and to keep the burden of expense within reasonable bounds.

The fact that the best and most practicable of supports is obtained by flushing refuse material into the openings having been determined, it remains to ascertain the sources of supply of this material, and the practicable methods of handling it.

We would classify the materials obtainable, in about the following order:

CULM FROM OLD AND FROM FRESH-MINED BANKS.

Culm is now being used for flushing mine workings. We make no further comment, excepting to refer to the test of its compressibility, and to the fact that we had opportunities to observe the methods of distribution of the material underground, and to note the apparent support given to the existing coal pillars and to the overburden.

SURPLUS MINE ROCK.

The second source of supply of material, in the order of availability, we believe would be the surplus mine rock that is produced in the mining of the thin beds of coal where either roof or floor must be removed to make height. It was observed in most of the thin beds visited that considerable quantities of this material are handled, either being stowed in the chambers or loaded into mine cars and hauled to some distant point to be unloaded by hand into abandoned mine openings. While this stowage of gob affords some measure of support to the coal pillars and the roof, the compressibility of the material, as shown by the tests, is so great that the material if put in by ordinary stowage is practically useless as an effective support, particularly at great depths. We believe, therefore, that this material should be loaded into cars, hauled outside, and handled over an efficient dump and through crushing rolls of proper design for pulverizing hard materials. The ground material should then be flushed, with the culm produced at the mine, into the portions of the mine workings where it will do the most good.

In addition to this source of supply of filling material, it would probably be found practicable to install handling and crushing machinery at each of the mining operations within the city limits, to pick up refuse material, such as old rock banks, ash banks and slag, and to grade off humps and hills of earth and comparatively soft rock, and to treat this material in the same manner. The cost of handling and flushing such foreign material in connection with the going operations of the several mines, would, of course, be very much less per cubic yard than it would be in the case of an independent plant established for obtaining and handling flushing material elsewhere.

RIVER SAND.

The next source of supply of material for flushing purposes, and one that we deem of considerable importance, is the Lackawanna River. It is a well-known fact that this stream of water carries in suspension large quantities of culm, sand, and loam at all times, and especially during the flood season. Of course it is impossible to determine without careful tests the quantity of this material in cubic yards, but we do not hesitate to express the opinion that there is enough of it, and will continue to be, to justify the establishing of settling basins and of a pumping plant for distributing the material thus impounded to points in the mine workings where artificial pillars are to be inserted.

To utilize this source of supply, it would, in our opinion, be advisable either to purchase, or to procure long-term leases on, river-bottom lands at various points where suitable catch basins could be excavated, and to procure a site for a central pumping plant for the purpose of handling this material. When such a plant is established, arrangements could be made to let down from the catch basins, at points upstream, the accumulated material; this would be carried by the stream to a central basin somewhere within the city limits.

We believe similar impounding basins on a smaller scale might be practicable on Roaring Brook, and that such material, if gathered at a higher elevation, might be flushed to near-by mine workings by gravity.

CITY REFUSE.

Another source of supply of material for flushing purposes would be city ashes and refuse from the streets and catch basins; also material from cellar excavations, grading of streets, parks, etc., which of course would have to be put through a crushing plant and reduced to such a size that it could be handled by flushing. For the proper distribution of the material just mentioned it would be necessary to drill bore holes to the mine workings at convenient points in the city streets and alleys—preferably in the latter, because there would be less interference with traffic. The necessary water for flushing this material would, of course, be supplied from the central pumping plant on the river or from the Roaring Brook gravity supply.

SAND FROM DISTANT POINTS.

Another important source of supply of material which we believe would be practicable would be sand and loam that the transportation companies should bring in from distant points along their railroads, where it can be most economically procured, in returning empty coal cars. This material would have to be dumped over a suitably arranged hopper and flushed into the mines with culm and other material.

A comparatively cheap and effective means for transportation of flushing material on the city streets to the shallow shafts and bore holes suggested would be to arrange with the traction company to haul the stuff in suitably designed hopper-bottom cars from the central crushing plant during the time of light traffic at night.

We would suggest the establishment of about four crushing plants so designed as to be easily knocked down and moved to other locations. The material to be handled by these plants should be taken from points where grading of humps and hills will result in the improvement of highways, parks, and private or public lands.

In this connection we would refer to the very extensive grading operations carried on in Seattle, Wash. A large section of the business center of that city was regraded mainly by the hydraulic method. Hills 100 feet high were cut or washed away, buildings were shored up or torn down, and the general level of the regraded section was lowered 10 to 30 feet. The material was flushed into Puget Sound by streams of water, and large areas of new land were formed over the low tide marshes along the bay shore. The expense was met by a general city-improvement tax.

PLANS, SPECIFICATIONS, AND COSTS.

The general nature and wide scope of this report necessarily limit us to general plans, specifications, and estimates of cost. The rendering of detailed plans and specifications and of exact estimates of cost can be made only after careful and exact surveys under particularly ascertained conditions; such surveys should be obtained from the engineers who are to be in charge of the execution of the work recommended in this report, in case it shall be entered upon by the authorities. We therefore explain by way of specifications what will be necessary in our opinion, what we recommend to be done to ameliorate the present conditions, and the approximate cost thereof.

We have made careful investigations of the resisting power of the various devices thus far used for supporting the roof at various places under this city, and also of other devices we were cognizant of or have ourselves originated, but the supporting values of these various devices, as indicated in the tables of tests presented, have convinced us that the method of flushing material into the mines by means of water is the best and only well-tried method.

The method we have originated and experimented upon to some meager extent—that of providing roof support by simultaneously blasting the floor and the roof of the coal mine to form a permanent pillar from the débris resulting from the blasting—is an economical one, and has its advantages for certain special localities where the overburden is light. Still, the amount of compression to which the pillars of this sort would be liable is considerable and the extent of the possible disrupting effect of the heavy blasting upon the strata is unknown. Consequently, much more extended and practical experiments or tests of the method must be made before its value and importance as a roof supporting device can be established.

Therefore, the only method we feel like recommending, after a careful study of the conditions, is the flushing method.

As before mentioned, the best protection for the surface from caves would require the complete filling of the mine openings with culm, sand, or other form of material, and even then there would be more or less subsidence if pillars were removed and filled-in material were substituted. The excessive cost of completely filling the openings, and the tremendous magnitude of the project makes this plan prohibitive.

In our opinion reasonable protection can be afforded by the introduction of artificial pillars of flushed material, reinforcing the natural coal pillars to the extent of relieving them of one-third of the overburden. Such artificial pillars to be located about as follows, reference being had particularly to the plans shown in Plates 1 to 24, which are part of this report.

Owing to the great importance of substantial support for school properties, we would suggest that in each bed mined under any school, for at least 50 feet outside the lot limits, or rather for a distance equal to one-half the depth of a bed below the surface, the openings be flushed full of the best available material. The school properties—being located in all parts of the city, and over widely varying mining conditions—would afford good starting points from which to space the additional artificial pillars necessary for the protection of the surface elsewhere.

Following out the above scheme in systematic order, we would recommend the installation of artificial pillars of flushed sand or flushed culm at each street intersection where the city blocks are of the usual size, about 5 acres, the present coal pillars to remain. In the case of all coal beds of greater depth than 150 feet, such pillars, if at the block corners, might be sufficiently near together; but for less depth the strata might be too weak to bridge the whole width of a city block, even though the usual coal pillars were left in place. Therefore it would be better, in the latter case, to install pillars in the center of each block also, in which case the pillars should each be about one-half as large as if located at the block corners only.

In locating artificial pillars intermediate between school properties, advantage should be taken of those places already flushed by the coal companies. It will be found that considerable filling of this sort has been done.

The question of the size and consequent cost of artificial piers is approached by us with much hesitation and caution, because, although we have secured considerable valuable information on the subject through the underground investigations we have been making, we know that in the last analysis the size of these piers must be estimated from the results of the testing we have done at the Fritz engineering laboratory at Lehigh University. In view of the great magnitude and importance of the question at stake, we realize that these tests, which are the first of the kind that have ever been made, are very meager and do not constitute a sufficient foundation upon which to base final conclusions.

Therefore we have decided to use a factor of safety of two. In other words, the size of the pillars we have recommended is twice as large as the tests indicate might be necessary. These tests are subject to check by further tests and other data that may be procured later, either through the working out in practice of the recommendations herein made, or otherwise, but which have not been and are not now available to us.

The size of artificial pillars should be determined by the local conditions found at the exact spot chosen upon inspection by the engineer in charge of the work. Subject to the above observations, the horizontal areas of artificial piers of flushed material confined in mine rooms are indicated in detail by the table following.

TABLE 5.—*Horizontal area, in square yards, of artificial mine pillars of confined flushed culm or flushed sand required under various permissible compressions to sustain one-third of the overburden of one city block of five acres, at various depths.*

Ultimate uniform compression permitted.	Depths.					
	25 feet.		50 feet.		100 feet.	
	Culm.	Sand.	Culm.	Sand.	Culm.	Sand.
Per cent.						
3	3,424	800	6,848	1,600	13,696	5,200
5	2,122	452	4,244	904	8,488	1,808
10	848	176	1.696	352	3,392	704
	200 feet.		400 feet.		800 feet.	
3	(a)	6,400	(a)	12,800	(a)	(a)
5	16,976	3,616	(a)	7,232	(a)	14,464
10	6,784	1,408	13,568	2,816	(a)	5,632

[a] Openings filled.

NOTES.—1. Up to 3 per cent compression, piers of sand and gravel concrete might be only one-half the size of sand piers, but for weights that would produce greater compression they are worthless.

2. One city block of 5 acres covers 24,200 square yards.

3. In fixing upon the amount of compression that might be permitted, consideration should be given to the fact that where several beds are to be filled, the total settlement will be several times as great as for one bed of the average thickness.

4. It will be noted that complete filling with culm is necessary for the compression mentioned at depths of 200 to about 500 feet, whereas for greater depths the compression due to the greater weight would be excessive. Sand, on account of its greater strength, is suitable for filling all beds at all depths under the city of Scranton, and is therefore to be preferred.

The location of bore holes or shafts through which to flush the material must be determined by the engineers in charge of the work. Several of the blocks can be reached from the foot of each bore hole or shaft.

In many of the beds on the west side large areas of the mines are inaccessible, and conditions are of such a character that we are thereby limited to the most general specifications. We would suggest first, that the school properties be taken as starting points, and under each of them, namely, Nos. 13, 43, 12, 29, 32, 32 annex, 14, 31, 16, 17, 18, 19, 41, 21, 40, 24, 22, 23, 25, 26, and 44, artificial piers of flushed material be installed wherever possible, these piers to extend well beyond the lot lines (at least 50 feet outside) in all the beds that have been worked, beginning with the lowest bed; and that when a pillar is built in that bed, the overlying beds be filled in order.

Early attention to schools Nos. 12, 23, and 29 is especially important. In locating the supporting pillars advantage should be taken of the large areas that are caved and closed in the Clark, New County, Big, Rock, and Diamond beds, and of other parts that are already flushed. The best results will be obtained, of course, by flushing the lowest beds first and proceeding upwards, care being taken to locate the new pillar in the upper seam over that already in place in the seam below.

COST OF SUGGESTED PROTECTIVE MEASURES.

The absence of accurate and conclusive data, and the many uncertain factors entering into this general statement make any submitted figures approximate only. Assuming that all the sources of flushing material hereinafter mentioned in the order of their importance and value—first, sand and loam brought from a distance in returning empty coal cars; second, culm from breakers and washeries; third, crushed mine rock, gob, etc.; fourth, culm and silt from Lackawanna River and Roaring Brook; fifth, crushed rock from three or four plants (which might be established by the protective commission)—are utilized in regular and systematic order, and that the methods of procuring water for flushing, etc., as suggested, are put in effect, we would in that case estimate the cost of the measures suggested about as follows:

The necessary plants and machinery for expeditiously excavating and loading the sand and filling material at distant points, and the plants in the city for unloading and transferring the material to the traction company cars for delivery at night to the various flushing points; the building of the dam and pumping stations on the Lackawanna River and the necessary storage dams at various points on the river above the city, for catching surplus sediment during seasons of high water; the dam in Roaring Brook, above the city level; the necessary means to conduct the water to the more elevated parts of the east and south sides; and a portable crushing plant to be located at the flushing points to crush the larger particles of sand, coal ashes, and city refuse that may be delivered and mixed with the flushing, would cost approximately $500,000.

The necessary facilities outlined above for the expeditious and economic handling of material and prosecution of the work having been provided, it is our opinion that artificial piers may be established in various beds at about the cost shown in the following table, using the factor of safety (2) mentioned above.

Table 6.—*Approximate cost per foot of coal-bed thickness of artificial mine pillar of confined flushed culm or flushed sand required under various permissible compressions to sustain one-third of the overburden of one city block of five acres, at various depths.*

Ultimate uniform compression permitted.	Cost.					
	Depth, 25 feet.		Depth, 50 feet.		Depth, 100 feet.	
	Culm.	Sand.	Culm.	Sand.	Culm.	Sand.
Per cent.						
3	$286	$266	$572	$532	$1,144	$1,064
5	176	150	352	300	704	600
10	70	60	140	120	280	240
	Depth, 200 feet.		Depth, 400 feet.		Depth, 800 feet.	
3	[a] $2,016	$2,128	(a)	$4,256	(a)	[a] $8,070
5	1,408	1,200	(a)	2,400	(a)	4,300
10	560	480	$1,120	960	(a)	1,920

[a] Filled.

The approximate cost per foot of bed thickness for each acre of complete flushing under schools and elsewhere, to take the place of pillars, if removed, would be:

For culm below level of river	$405
For sand above or below river	1,615

If, in the case of the coal beds 150 feet or more deep, the board of control concludes to be satisfied to relieve the present pillars under the schools of about one-third of the burden they now sustain, the approximate cost of so doing, per foot of bed thickness for each acre thus protected, will be about one-fifth of the cost shown in Table 6, for the same depth, material, and settlement. For example, to relieve the present pillars of the Clark bed, which is about 200 feet deep under the central city and hill sections, of one-third of the weight they now sustain, allowing 5 per cent as ultimate permissible settlement for the coal-bed roof, would cost per foot-acre of coal bed, about $280 for culm flushing, if the piers are below the river level; or $240 for sand flushing, whether above or below the river; and since this coal bed is about 7 feet thick, the total cost of such piers would be about $1,960 and $1,680 per acre, respectively.

The above table is estimated on the supposition that the pillars of flushed culm would be installed only at points that are in coal beds below the level of the river (so the necessity of pumping culm to an elevation above the river would be avoided) and that piers of flushed sand would be installed in coal beds at locations that are above the level of the river, or at any location where such sand pillars would be convenient and not more costly than culm pillars.

It will be noted that there is no large difference in cost between culm or sand. This, of course, is on account of the greater efficiency of the sand, a less quantity of which is required to give the same supporting power.

It will be apparent that much of this work can be done by the systems of flushing already in service at the several mining plants, and that in order to accomplish the best results in the most economical manner, the plans of the city mine-cave protective commission must be made in harmony with the already established systems of the mining companies. It is manifest that all underground work should be done in cooperation with the coal companies and that the water flushed into the mines must be pumped by the plants already installed, with such additional equipment as may be found necessary.

Therefore, this matter of harmonious plans and procedure between the coal companies, the city, the school authorities, and the public is essential to the successful carrying out of any relief measures that are herein or may be hereafter suggested. It is a fact that should be evident to all that the prosperity of the city and the community is to a large extent dependent upon the coal companies, so that drastic laws or regulations that may curtail the mining of coal will necessarily react on the prosperity of the community, whereas any ameliorating plans or compromises which it may be possible to effect between the city and the mining companies tend to prolong the life of the mining industry in Scranton and vicinity, and should be promoted.

It should, therefore, be the aim of all persons interested in mine-cave protective measures and of the companies operating the mines to adopt plans that will best conserve the welfare of all concerned.

The expenditure for the work would, of course, be distributed over many years, the relief measures being applied at the points most in need of protection and as rapidly as proper arrangements could be effected and the necessary details, surveys, etc., prepared.

For the business-like carrying out of the plans suggested, it is recommended that a protective commission be established, consisting of not less than three nor more than five men representing the city authorities, the school board, and the coal companies; this commission to have full and complete authority for the execution of the plans, after approval by the proper legal action. The commission should employ an engineer as active manager of the work, who should devote all his time to the service.

GENERAL CONCLUSIONS.

In concluding this somewhat lengthy report, we are of the following opinion:

First. Speaking broadly, the surface of the city can be supported by the methods recommended, and at a cost not in any sense prohibitory when considered with relation to the value of the property and the activities for which support is absolutely essential.

Second. Although there are points in the city, as indicated in the detailed report, where at the present time in our judgment there is distinct and immediate danger to life and property, yet the total area immediately threatened constitutes but about 15 per cent of the entire area of the city, and the danger is mainly from workings in surface beds.

Third. On the west side the beds of the middle series are thick and close together and the pillars are not columnized, creating a dangerous situation where the workings have not been closed by previous caves. Particular areas thus threatened can not be definitely specified on account of the inaccessibility of much of the mined-over area. Detailed investigation should be made of the portions of the mines not already closed. Relatively, we do not believe that a large part of the territory mentioned is threatened because so much ground has been already closed by caves.

Special attention is called to the conditions under schools Nos. 13, 23, and 29. They should be attended to promptly.

The beds of the lower series, namely, the three Dunmores, are so thin and so far below the surface that with the usual system of mining we do not think they constitute a serious menace to the improvements on the surface, except along the margin of solid blocks of unmined coal and near the outcrops. In the deep-lying parts of the Dunmore beds we believe these solid blocks should be mined.

Fourth. It would seem, therefore, to be not only the part of wisdom, but absolutely obligatory to commence at once to give support to the points menaced, and thereupon proceed upon a general policy of giving support to the entire area of the city; for it must be borne in mind that with the mining activities that are constantly going on other and additional points of danger are not only liable to, but in all probability will, develop with each passing year—it might almost be said with each passing month.

Fifth. Where the owner of the surface has undoubted right to the support thereof by coal pillars, in our opinion he could permit the removal of such pillars; the value of these would under average conditions pay for such artificial support as we have recommended, assuming that the pillars were mined and the support constructed by the same operating company. This observation, however, is based upon the assumption that in such case the operating company would be one of the large transportation companies, inasmuch as while there might not be a profit in the immediate transaction of mining the pillars and installing the support there would, of course, be a profit to such companies in carrying the coal to market.

Sixth. Culm flushing should be used only in coal beds having light cover, up to 200 to 500 feet, according to the amount of settlement expected. But sand, being four or five times as strong as culm, is better, is suitable for all beds under Scranton and should be preferred.

Seventh. We believe that the conclusions adduced from the tests made, and the calculations and tabulations based thereon, are reasonably reliable; yet we desire to record the opinion that there are conditions existing in the mines to which they might not apply—for instance, in localities where several seams of coal are separated by a thin layer, or layers, of shale and slate, or even sandstone, and the pillars in the several seams are not over one another, and it is proposed reclaiming all or any part of the pillars.

Even though an application of the above tables might appear to fit the conditions, we believe that the only permissible procedure would be to first fill with flushed material all of the openings in the lowest bed of the series and then fill upward until all the beds are filled, care being taken to have the flushed areas over one another. After all of the openings in all of the seams have been filled, the pillars in the uppermost seam may then be attacked; as each pillar is removed, the space should be at once filled. No pillar reclamation should be permitted in any of the other beds until all of the pillars in the upper bed have been removed and the overburden has come to rest on the flushed material; then the pillars in the next lower seam may be attacked and handled in like manner.

NOTES ON SAND FOR MINE FLUSHING IN THE SCRANTON REGION.

By N. H. Darton.

INTRODUCTORY STATEMENT.

This report presents the results of field studies in the vicinity of the city of Scranton, Pa., to find some convenient sources of sand to be used for filling chambers in coal mines under the city. Attention was given only to material that lies at higher altitudes than the workings and might be hauled down grade or transported by water to the mines. Moreover, it was recognized that inasmuch as the final means of transportation underground would be flushing with water the material would have to be in granular condition. The sources of supply are glacial till of various kinds and the rocks of the coal measures or underlying formations. The latter would have to be quarried and crushed; the pebbles and bowlders of the till could be crushed or discarded.

ROCK FOR CRUSHING.

The entire anthracite region is underlain by rocks that contain a large proportion of sandstone suitable for crushing, and can yield an angular sand of great strength. It is estimated that sandstone of moderate hardness can be crushed into coarse sand for $0.50 to $0.60 a ton, including quarrying. This estimate is based on a cost of $1.60 per ton for coal for power.

One of the most conspicuous rocks in the Scranton region is the Pottsville conglomerate. It immediately underlies the coal measures and outcrops in belts of varying width in the mountain slopes on both sides of the coal field. The greater part of this rock is too hard to be cheaply crushed into sand. It is underlain by greenish and gray sandstones, mostly soft, and in places by red shale. These sandstones and the shale can be more easily crushed. The most extensive ledges of sandstone convenient to railroad haulage are in the gorges of Roaring Brook east of Scranton, and of Leggetts Creek, northwest of the city. Along the gorge of Roaring Brook from Moscow to Dunmore there are continuous high ledges, many of which rise 500 to 700 feet above the creek. This gorge is followed by the Erie and the Lackawanna railroads with a heavy down grade into Scranton. There are many localities favorable for the establishment of quarries and crushers, and the possible tonnage of product is practically unlimited. It is certainly sufficient to fill all coal workings under the city of Scranton. One crushing plant is already in operation by the Nay Aug Stone Co., just below Nay Aug station. However, a large amount of stone is available farther down the gorge and therefore considerably nearer Scranton. Crushed rock from a quarry in this gorge could be loaded directly on empty coal cars and hauled down grade into Scranton.

The sandstones underlying the Pottsville conglomerate in the gorge of Leggetts Run present a thickness of about 800 feet, rising in high walls along the gorge 2 miles northwest of Providence. There is here available a very large amount of sandstone of moderate hardness, admirably located and physically well suited for sand for filling. The product could be hauled down grade on the Lackawanna Railroad or on the trolley line which follows the bottom of the gorge.

The hydraulic transportation of the fine crushed stone to the mine was not especially considered, but both on Roaring Brook and on Leggetts Creek the waters are so impounded that perhaps they are not continuously available for hydraulic work. The sandstones under the Pottsville conglomerate are exposed also in the valley of Meadow Brook in the southern part of Scranton, where they are utilized by the crusher now in operation. This crusher belongs to the Meadow Brook Co. and has a capacity of about 300 tons a day. Crushed stone from the exposures in this vicinity would be handled by the Laurel line and the Erie Railroad; possibly, also, it could be flushed down the bed of Meadow Brook, but the conditions are much less favorable for such tranportation than on Roaring Brook or Leggetts Creek.

There are extensive ledges of the sandstones of the coal measures in the high ridge extending west from Lackawanna River, just east of Holden, where a moderately large amount of gray sandstone is available. Another ledge appears on the north bank of Leggetts Creek, near its mouth. This ledge has been quarried extensively, but the quarry could be extended over 1 or 2 acres to the north. To the northwest it passes under the huge pile of culm from Leggetts Creek colliery. Sandstone ledges outcrop prominently in the high ridge on the east bank of Lackawanna River, a half mile east of Dickson, and a crusher could be established at this place with fair advantage, as the ledges are directly over extensive coal workings.

GLACIAL TILL.

The till left by the great continental glacier extends across northern Pennsylvania, and forms a mantle of irregular thickness and varying composition. In the Scranton region it covers much of the surface to a considerable depth, excepting the mountain slopes and summits, where it is thin or absent. The underlying coal-measure rocks also appear in places along the lower slopes of the

Lackawanna Valley, and near the river there are terraces of later alluvium. Where the till is thick it rises in hummocky ridges that are generally thickly strewn with bowlders. Scranton is built mostly on slopes of till, terraces of rearranged till material, and later beds of sand deposited by Lackawanna River.

The glacial till consists of a mixture of sand, clay, loam, gravel, and bowlders in varying proportion. In the Scranton region the till contains little clay and a predominance of sand, but I saw no extensive deposits of pure sand. Gravel and bowlders exist in all the exposures and their proportion is seldom less than 50 per cent. Some streaks of pure or pebbly sand occur, but they are local and would not yield a large supply. If the sandy till were subjected to washing by hydraulic jets and sluiceways the sand would all be separated from the bowlders. This till, in my opinion, is the best source of sand in the region; it can be removed at many places where the cultural and hydraulic conditions are favorable. One of the most desirable sources of supply would be from street grading, since the result would be both a large volume of sand and a city improvement. The bowlders remaining after the sand had been carried off could be crushed into sand and washed into the sluiceways.

In the northern part of Providence there are several prominent hills or knolls of sandy till which could be leveled to advantage. They lie between Bloom and Keyser Avenues, west of West Market Street; another knoll lies just east of West Market Street, north of Clark Avenue. These knolls rise from 50 to 60 feet above the average grade of the streets and would furnish nearly a half million tons of material. The material contains about 50 per cent of sand; the remainder is gravel that would have to be crushed in order to be utilized for flushing. Two very much larger masses of till lie on the mountain slope a short distance north and west of this area and another extends up the ridge on the north side of Leggetts Creek. Each of these three areas contains about a million tons of sandy till. Similar masses of till lie on the lower slopes of the mountain west of Keyser Creek, the largest one extending to within a few hundred yards of the Hyde Park colliery. There is a rock core to this largest mass, but the till is not less than 50 feet thick, and the indicated total tonnage for this one area is about 15,000,000 tons. The deposit is mostly sandy till with only a small proportion of clay; it averages nearly 50 per cent sand. The remaining material is coarse bowlders, mostly of hard rocks, which might either be crushed into sand or left on the ground after the sand is washed out. There is in this vicinity only a meager supply of water for hydraulicking.

An extensive area of sandy till is just east of the Holden colliery. It underlies land that for the greater part is not covered by buildings, and has an estimated tonnage of about 5,000,000 tons. The material contains about 50 per cent of sand, with gravel, bowlders of hard rock, and very little clay.

One of the most desirable bodies of sandy till is on the estate of William Miles, just west of Olyphant. The land is not built on and is adjacent to various lines of railroads. A moderate amount of water is available for sluicing in a near-by creek, and water possibly can be had from the river also. The till area measures about 2,000 by 1,500 feet, and the thickness of material available is about 30 feet. These measurements indicate an aggregate of nearly 5,000,000 tons. The proportion of sand is variable, but in places it exceeds 60 per cent. It is being dug to a small extent for sand for local building purposes. There is not sufficient clay in any part of the area to be disadvantageous, and the gravel and bowlders could be crushed, if desired.

ALLUVIUM.

Along the Lackawanna River extend low alluvial terraces, which are underlain by sand that in greater part contains only a small proportion of coarse material. Unfortunately, however, the sand area near Scranton is covered with houses or is held for its value as building lots, so that the sand is not available except at a few points. As the terraces are very low, the tonnage of sand that could be obtained is not great. It is possible that the water of the river could be used for sluicing this material, but because of the great variation in the amount of water available during the different seasons of the year, the conditions are not altogether favorable. The location of the railroads along the river complicates the problem of removing the sand. Doubtless this source of material would not be as advantageous as the sandy till or crushed rock.

RIVER SAND.

The most extensive deposit of sand in the northern anthracite coal basin is under the deep valley of the Susquehanna River from Pittston to Nanticoke. Its width averages 2 miles for a long distance and its thickness varies from 100 to 200 feet in greater part. There are many places where this material could be lifted from the river channel by dredges and loaded on empty coal cars. In the river and harbor work of the United States Engineers office and in Panama Canal excavations sand is dredged from depths of 20 to 40 feet and carried in pipes 1,000 to 2,000 feet at a cost of 3 to 5 cents a cubic yard. The cost of handling sand from the Susquehanna River is a matter for local engineers to determine. The sediment brought down by the river, especially in time of flood, would rapidly refill excavations made by dredging.

APPENDIX.

COMPRESSIVE STRENGTH OF ANTHRACITE COAL.[a]

Owing to the general lack of knowledge among the engineers of the anthracite coal field as to the compressive strength of anthracite coal, and in view of the very important matters relating to the economy of mining of anthracite, which depend directly upon this subject, the Scranton Engineers' Club, in July, 1900, appointed a committee to make a general investigation of the compressive strength of anthracite coal, having reference particularly to the northern anthracite field. This table contains the results of the efforts of that committee, in a condensed form. The committee sent circular letters to the various anthracite operators in the northern field, requesting them to contribute to the efforts of the committee by sending samples in triplicate to be tested. These samples were requested in three sizes, viz.:

Two inches square on the base by 1 inch high, indicated in the table as "1."

Two inches square on the base by 2 inches high, indicated in the table as "2."

Two inches square on the base by 4 inches high, indicated in the table as "4."

These samples were requested to be prepared in each case with the base parallel to the bedding plane of the coal seam, and the height at right angles thereto.

Generous responses to this circular letter were received in the form of some 425 samples for testing, a few of which were defective and not tested. These samples were then divided and sent to the following colleges for testing, the professors named very kindly offering to assist the committee by making the tests:

To Prof. R. C. Carpenter, of the department of experimental engineering, Sibley College, Cornell University, Ithaca, N. Y., 133 samples.

To Prof. Mansfield Merriman, professor of civil engineering, Lehigh University, South Bethlehem, Pa., 177 samples.

To Prof. Louis E. Reber, dean of the school of engineering, Pennsylvania State College, State College, Pa., 113 samples.

After these samples were tested and the results returned to the committee, they were tabulated in a detailed way, forming an immense table, of which this accompanying table is a condensation. The following description of it is given, that the reader may the better understand it:

1. The collieries from which the tests were taken are arranged in the column on the left, in order, according to the location of the collieries, beginning at the northerly end of the region near Forest City and ending with the southermost collieries from which tests were received, at Williamstown and Lykens, in the southern coal field.
2. The coal beds are arranged at the top of the table in the order of their occurrence in the measures, the highest beds being at the left, and the lowest beds at the right. Where local names for the beds differ from the general names, their local names are inserted in the body of the table.
3. The tests are arranged in vertical double columns under the several coal seams, and each test is placed in the column under its respective coal bed and in the horizontal line opposite the colliery from which it was taken.
4. Results given in this table are in pounds avoirdupois per square inch of horizontal area.

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[a] Printed by permission.

5. The items given in the columns under the coal double-bed headings are the "First crack," indicating the pressure in pounds per square inch required to produce the first crack in the sample. In other words it is the pressure which would cause the coal of the same quality as the sample to begin squeezing. The items under "Maximum load" in each case indicate the pressure in pounds per square inch at at which the sample crushed. The items under the head of "No. of tests" indicate the number of tests taken from the respective beds in the several collieries, the average of these tests being represented by the figures in the table.

6. The horizontal line headed "General average" contains the average of all the tests under the respective coal beds as indicated.

The next horizontal line under "General average" indicates the percentage of the maximum load which is represented by the pressure necessary to produce the first crack, or the squeezing pressure. And the second horizontal line under the general average shows the percentage which tests 2 and 4 bear to test 1 in each case.

The grand average, or net result, is contained under a separate heading, and indicates generally the average squeezing and crushing strength as shown by the samples tested. The tests from the several coal fields are tabulated separately, and clearly show the superior strength of the harder coals and the weakness of the softer.

7. From an inspection of this table, the following results appear to apply, approximately:

That the squeezing strength of a mine pillar whose width is twice its height is about 3,000 pounds to the square inch, and the crushing strength about 6,000 pounds per square inch, or, approximately, twice as much. And in general, other things being equal, the crushing strength of mine pillars would vary inversely as the square root of the thickness of the bed.

The same general rule apparently holds true, also, for the squeezing strength in all cases where the height of the pillar is less than its width. In tall pillars having a height greater than their width, the squeezing strength apparently remains nearly constant, while the crushing strength continues to diminish with height according to the above rule.

WM. GRIFFITH, *Chairman*.	HARRY E. YEWENS,
J. H. FISHER,	H. H. STOEK,
MORGAN DAVIS, Jr.	J. T. BEARD,

Coal-test Committee, Scranton Engineers' Club.

Compressive strength of anthracite coal.

NORTHERN COAL FIELD.

Collieries.	Height of sample.[a]	Kidney.[b]			Olyphant No. 2, Hillman.			Diamond.			Rock.			Big Baltimore.			New County.			Clark Ross—Arch.			Dunmore Red Ash.			Dunmore No. 2.			Dunmore No. 3.			Grand average.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
																	Top coal.			Bottom coal.														
Vandling[b]	1																2,971	5,663	2	1,475	8,749	3	4,423	7,531	3									
	2																2,762	4,425	2	2,569	5,239	3	2,113	7,637	3									
	4																1,800	2,787	2	1,410	2,012	3	1,975	3,318	3									
														Mills.																				
Coal Brook	1													2,901	6,187	3																		
	2													986	3,150	3																		
	4													1,200	2,079	3																		
																	Three-foot.																	
Erie	1																3,000	8,087	1	1,500	3,425	1												
	2																1,500	2,182	1	1,525	1,975	1												
	4																1,250	1,780	1	455	1,872	1												
														Grassy.																				
Jermyn, D. & H.	1													5,410	9,891	3				2,564	5,619	3												
	2													2,541	7,415	3				4,041	5,841	3												
	4													5,053	6,653	3				1,848	2,332	3												
Olyphant	1				1,825	6,026	3	2,325	5,176	2	1,822	6,316	3	2,792	6,720	3																		
	2				1,131	4,020	3	4,485	7,301	2	1,167	2,785	2	1,628	3,614	3																		
	4							1,460	3,233	3	1,536	2,565	2	3,017	3,741	2																		
Marvine	1							2,868	4,674	3				4,764	4,765	3				4,781	6,963	3												
	2							1,014	1,309	3				802	3,947	3				2,704	5,275	3												
	4							1,398	1,828	3				1,895	2,741	3				1,562	1,600	3												

[a] Test samples 2 inches square by 1 inch high indicated by 1. Test samples 2 inches square by 2 inches high indicated by 2. Test samples 2 inches square by 4 inches high indicated by 4.

[b] The coal beds are arranged in order as they occur, that is, highest on left and lowest on right. The collieries are arranged in order as located, that is, northern at top and southern at bottom. All tests in pounds per square inch.

Compressive strength of anthracite coal—Continued.

NORTHERN COAL FIELD—Continued.

Collieries.	Height of sample.	Kidney.			Olyphant No. 2. Hillman.			Diamond.			Rock.			Big Baltimore.			New County.			Clark Ross—Arch.			Dunmore Red Ash.			Dunmore No. 2.			Dunmore No. 3.			Grand average.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
D. & H., Scranton	1							2,331	3,260	2	2,319	4,266	2							2,854	6,107	2												
	2							1,454	3,011	2	1,811	3,221	2							2,545	4,251	2												
	4							1,530	2,578	2	1,346	1,630	2							2,382	3,941	2												
Leggetts Creek	1																1,869	4,882	3															
	2																1,662	2,784	2															
	4																1,279	2,832	3															
Dickson	1													3,685	6,381	3				4,113	6,274	3	2,343	3,228	3	3,821	4,821	3						
	2													3,900	5,426	3				1,575	3,001	3	1,668	4,330	3									
	4													1,657	1,819	2				865	1,720	3	1,650	2,195	3									
Cayuga	1										500	3,200	1							1,500	3,500	1												
	2										250	1,125	1							1,375	3,250	1												
	4										970	1,625	1							1,875	3,215	1												
					Four-foot.																													
Von Storch	1				5,881	6,426	3	2,500	5,000	1	2,875	5,500	1							2,750	5,462	1												
	2				2,336	4,102	3	1,500	3,500	1	1,820	4,125	1							2,250	3,960	1												
	4				1,930	2,343	3	2,500	3,200	1	3,000	3,941	1							2,250	3,045	1												
D., L. & W., Scranton	1													5,000	7,000	1	2,000	4,000	1															
	2													875	2,250	1	1,735	1,947	1															
	4													520	645	1	1,537	2,120	1															
Bellevue	1																3,500	6,875	1	2,000	5,700	1	2,500	4,500	1									
	2																3,125	4,000	1	3,625	4,990	1	2,375	3,625	1									
	4																4,315	4,625	1	1,705	2,000	1	1,500	2,000	1									
Holden	1										2,675	4,575	1				2,000	8,970	1	2,137	4,890	1												
	2										1,132	4,165	1				1,800	1,800	1	2,000	3,500	1												
	4										930	1,160	1							1,795	4,125	1												

Greenwood	1																									4,250	6,537	3						
	2																									1,937	5,704	3						
	4																									1,887	2,350	3						
Langcliffe	1																												2,201	7,041	3			
	2																												2,258	3,803	3			
	4																												2,417	3,109	3			
William "A"	1																							1,812	3,766	3	5,075	7,646	3	1,287	5,253	3			
	2																							1,262	3,620	2	1,987	5,258	3	1,775	4,062	3			
	4																							1,440	1,895	3	2,488	3,577	3	1,800	2,141	3			
Buttonwood and Plymouth								Old Bennett.			Five-foot.																							
	1	3,407	7,929	3	1,765	6,569	3	3,017	7,038	3	1,727	6,273	3	900	4,085	3																		
	2	2,847	6,216	3	1,568	2,614	3	3,127	6,306	3	2,116	2,356	3	1,700	3,544	3																		
	4	2,150	3,031	3	1,157	2,547	3	3,309	5,391	3	1,990	3,665	3	845	3,182	3																		
Avondale	1																			2,017	4,195	2	1,994	6,519	2									
	2																			1,410	2,550	2	1,732	3,519	2									
	4																			1,425	2,249	2	2,259	3,275	2									
Alden	1							2,409	5,870	2				2,562	6,160	2							2,522	5,671	2									
	2							1,285	2,279	2				1,887	2,946	2							1,587	2,368	2									
	4							2,596	3,242	2				1,937	3,179	2							1,550	2,620	2									
Nanticoke		George.						Mills.																										
	1	1,500	4,250	1	2,875	7,975	1	6,000	7,000	1				6,600	10,892	1				6,500	7,802	1	6,500	7,500	1									
	2	3,490	6,635	1	1,055	1,845	1	1,337	6,500	1				4,395	4,395	1				1,500	2,115	1	1,125	3,402	1									
	4	1,250	3,082	1	1,627	1,860	1	1,125	2,512	1				1,250	3,750	1				1,305	2,360	1	2,315	3,000	1									
General average	1	2,930	7,009	4	3,132	6,504	10	2,877	5,407	14	1,940	5,416	11	3,550	6,566	22	2,450	5,985	9	2,951	6,054	22	2,917	5,330	15	4,378	6,335	9	1,744	6,147	6	2,978	6,014	122
	2	3,008	6,321	4	1,618	3,409	10	2,122	4,144	14	1,551	2,850	10	1,990	4,266	22	2,126	3,043	8	2,402	4,157	22	1,714	4,424	14	1,957	5,480	6	2,016	3,933	6	2,025	4,087	116
	4	1,925	3,044	4	1,557	2,365	7	2,025	3,247	15	1,673	2,611	10	2,101	3,295	20	1,817	2,824	8	1,548	2,363	22	1,775	2,601	15	2,220	2,947	6	2,108	2,625	6	1,848	2,800	113
																																		351
Proportion 1: First crack ÷ max. load, i. e., percentage	1	42	100		49	100		53	100		36	100		54	100		41	100		49	100		57	100		69	100		28	100		48.4	100	
	2	47	100		47	100		51	100		54	100		47	100		70	100		58	100		39	100		36	100		51	100		49.5	100	
	4	63	100		61	100		50	100		64	100		64	100		64	100		65	100		68	100		75	100		80	100		65.8	100	
Proportion 2: Tests 2 and 4 ÷ test 1, i. e., percentage		100	100		100	100		100	100		100	100		100	100		100	100		100	100		100	100		100	100		100	100		100.	100.	
		105	90		52	52		74	77		80	53		56	65		87	51		81	69		56	83		45	86		115	64		67.	65.5	
		66	40		51	36		70	67		86	48		60	50		70	47		53	39		58	50		50	46		121	43		62.1	45.7	

Compressive strength of anthracite coal—Continued.

EASTERN MIDDLE FIELD.

Collieries.	Height of sample.	Kidney.			Olyphant No. 2, Hillman.			Diamond.			Rock.			Big Baltimore.			New County.			Clark Ross—Arch.			Dunmore Red Ash.			Dunmore No. 2.			Dunmore No. 3.			Grand average.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
														Mammoth.						Wharton.			Buck Mt.											
Hazleton No. 5	1	...	...	...	...	...	...	...	...	...	...	...	...	5,000	6,825	1	...	...	...	8,500	10,525	1	7,000	10,962	1	...	...	...	...	...	...	...	...	...
	2	...	...	...	...	...	...	...	...	...	...	...	...	2,830	3,547	1	...	...	...	4,500	5,400	1	5,000	5,000	1	...	...	...	...	...	...	...	...	...
	4	...	...	...	...	...	...	...	...	...	...	...	...	1,375	1,375	1	...	...	...	4,000	5,990	1	5,000	3,375	1	...	...	...	...	...	...	...	...	...
Hazleton No. 1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1,750	5,200	2	5,488	6,528	2	...	...	...	...	...	...	...	...	...
	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1,500	3,000	1	3,113	3,600	2	...	...	...	...	...	...	...	...	...
	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3,057	3,170	2	3,752	4,833	2	...	...	...	...	...	...	...	...	...
General average	1	...	...	...	...	...	...	...	...	...	...	...	...	5,000	6,825	1	...	...	...	4,000	6,975	3	5,992	8,053	3	...	...	...	...	...	...	4,996	7,417	7
	2	...	...	...	...	...	...	...	...	...	...	...	...	2,830	3,547	1	...	...	...	3,000	3,700	2	3,742	4,066	3	...	...	...	...	...	...	3,343	3,857	6
	4	...	...	...	...	...	...	...	...	...	...	...	...	1,375	1,375	1	...	...	...	3,371	4,110	3	4,135	4,347	3	...	...	...	...	...	...	3,413	3,821	7
WESTERN MIDDLE FIELD.																																		
														Mammoth.						Seven foot.			Buck Mt.											
Packer No. 3	1	...	...	...	...	...	...	...	...	...	...	...	...	3,000	9,892	1	...	...	...	1,552	9,500	1	4,450	6,500	1	...	...	...	...	...	...	3,001	8,631	3
	2	...	...	...	...	...	...	...	...	...	...	...	...	895	4,000	1	...	...	...	500	4,497	1	968	2,000	1	...	...	...	...	...	...	788	3,499	3
	4	...	...	...	...	...	...	...	...	...	...	...	...	1,945	2,500	1	...	...	...	1,370	3,000	1	1,005	1,842	1	...	...	...	...	...	...	1,440	2,447	3
SOUTHERN FIELD.																																		
														No. 9½ White Ash.			No. 9 White Ash.			No. 7 White Ash.			White's Vein.			Lykens Valley.			Little Lykens Valley.					
Williamstown	1	...	...	...	...	...	...	...	...	...	...	...	...	1,442	3,638	2	2,063	4,509	2	897	3,571	2	...	...	...	...	...	...						
	2	...	...	...	...	...	...	...	...	...	...	...	...	1,087	2,191	2	1,753	3,219	2	860	1,596	2	...	...	...	...	...	...	...	...	...	...	...	...
	4	...	...	...	...	...	...	...	...	...	...	...	...	1,515	2,152	2	841	1,150	2	1,361	3,127	2	...	...	...	...	...	...	...	...	...	...	...	...
Lykens	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	642	4,013	2	725	4,131	2	976	3,025	2	1,124	3,814	12
	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1,175	2,120	2	956	2,937	2	764	1,198	2	1,099	2,377	12
	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1,231	1,612	2	1,246	2,262	2	735	911	2	988	1,809	12
																																		416

COMPRESSIVE STRENGTH OF MATERIALS FOR ROOF SUPPORT.

A series of tests of various kinds of materials for supporting the roof in mine workings was made in the Fritz Engineering Laboratory at Lehigh University. The results are given in the following report:

SOUTH BETHLEHEM, PA., *January 26, 1911.*

MESSRS. WILLIAM GRIFFITH and ELI T. CONNER,
Scranton, Pa.

GENTLEMEN: I beg leave to state that we have concluded the series of tests on the bearing power of materials used in sustaining the roofs of mines, and beg leave to report as follows.

With the exception of a small quantity of sand, all of the materials which we tested were received from you, there being one carload which you sent us from the anthracite coal-mining district. The detailed descriptions of the various tests follow:

TEST NO. 1.

This test consisted of crushing a pillar made of mine rock, the four sides of which were laid vertically and then filled with stone of various sizes packed in by hand so as to make a pillar of loose stones without mortar of any kind. This pillar was 5 feet long, 2 feet 4 inches wide, and 18 inches high. It was laid directly on the bedplate of the testing machine and under three steel beams which were later used in applying the load over the entire top surface of the pillar. The stone used was slate, bony coal, and fire clay. The load on this pillar was applied in increments until a maximum pressure of 489,150 pounds was reached. The following table shows the loading at the different stages of the tests, together with the deflections caused by these loads. You will notice that when the total load was 489,150 pounds (approximately 42,000 pounds per square foot) the maximum compression amounted to 5.3 inches.

TEST NO. 2.

Loads and settlements of a rectangular pillar of mine rock.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
4,950	....	78,625	2.21	260,450	3.95
18,550	0.52	104,050	2.74	326,450	4.32
33,750	.97	130,350	3.15	396,940	4.83
46,350	1.40	233,200	3.75	489,150	5.26
63,025	1.81				

This test consisted in crushing a timber crib made of four layers of round timbers which were about 5 inches in diameter and were laid log-house fashion. Each of two of the layers consisted of two of those round timbers 5 feet 4 inches in length and each of the other two layers consisted of three round timbers 2 feet 8 inches in length. The spaces between these timbers were filled with slate, bony coal, and fire clay, and the crib was then filled with small stones shoveled in; the whole resulting in a timber crib 5 feet 4 inches in length, 2 feet 8 inches wide, and 23½ inches high. The load was applied in increments as shown by the following table. The maximum load reached 900,000 pounds and the maximum settlement was 7.1 inches.

Loads and settlements of a timber crib filled with mine rock.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
5,250	....	120,000	2.13	463,000	4.86
10,550	0.49	140,000	2.33	506,000	5.23
20,000	.78	179,800	2.72	604,000	5.80
30,000	1.02	220,000	3.09	669,000	6.10
40,200	1.21	260,000	3.44	728,600	6.38
60,200	1.48	310,000	3.80	780,000	6.71
80,400	1.74	370,000	4.17	800,000	6.87
100,000	1.95	413,000	....	900,000	7.08

TEST NO. 3.

This test consisted of crushing a circular pillar 28 inches in diameter and 14½ inches high, made of slate arranged so that the outer surface was fairly smooth, the spaces between the stones and the interior of the pillar being filled with small stones. The load was applied in increments as shown in the following table, the maximum load being 361,000 pounds, with a corresponding settlement of 4½ inches.

Loads and settlements of a circular pillar of mine rock.

Loads	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
4,000	....	71,200	1.29	195,400	3.15
20,000	0.19	98,000	1.48	238,500	3.69
37,000	.65	127,000	1.72	276,000	4.05
51,000	.75	150,000	2.50	361,600	4.51
60,200	1.08	183,000	2.82		

After tests Nos. 1, 2, and 3 the stones were found to be very badly crushed, many having been reduced almost to a powder, especially those immediately under the load.

TEST NO. 4.

This test consisted in loading a pile of broken stones and observing the settlement caused by the loading. The stone used was crushed sandstone which would pass through a ring 1¾ inches in diameter; it had 40 per cent voids, but under the bearing plate on which the load was applied the voids were filled with small broken stones so as to get a secure bearing. The pile of stone was 25 inches wide, 9¼ inches high, 2 feet 10 inches long on the top, and 4 feet 5 inches long on the bottom. The load was applied on a cast-iron bearing plate 20 inches square which rested on the top of the pile of stones. The following table gives the loads and the settlement. The maximum load reached was 581,000 pounds, and the maximum settlement was 4.4 inches:

Loads and settlements of a pile of crushed sandstone.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
1,400	....	44,000	1.73	292,000	3.73
2,450	....	81,400	2.38	437,000	4.10
21,000	0.87	141,700	2.97	581,000	4.36

After the test many of the stones were found reduced practically to a powder. The stones under the bearing plate were greatly disintegrated and the plate was pressed downward into the stones. At the ends the pile moved outward as the load was applied, but on the sides the pile was confined by timbers which prevented lateral movement.

TEST NO. 5.

This test consisted in crushing a pile of broken sandstone of various sizes up to pieces as large as a man's head. Small stones were placed under the bearing plate. The stones were confined on the sides but were free on the ends and were not laid in any order. The pile was 25 inches wide and 11¼ inches high; its length was 3 feet 8 inches on top and 5 feet at the bottom. The load was applied by a cast-iron bearing plate on the top of the pile, the plate being 20 inches square. The following table gives the loads and settlements. The maximum load was 417,000 pounds and the maximum settlement was 4.6 inches.

Loads and settlements of a pile of broken sandstone.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
6,500	....	50,000	1.06	194,300	3.21
21,000	0.32	72,500	1.54	266,000	3.74
25,000	.46	155,500	2.35	365,000	4.31
31,500	.61	164,400	2.66	417,000	4.61
33,600	.69				

TEST NO. 6.

This test consisted of applying a load to a pile of river sand by means of a 20 by 20 inch bearing plate. The pile was 8 inches deep, 2 feet 6 inches long on top, and 4 feet 2 inches long on the bottom, had a width of 25 inches, and was confined on the sides but not on the ends. The maximum load reached was 600,000 pounds, and the maximum settlement was 5 inches.

TEST NO. 7.

This test consisted in crushing a pile of broken sandstone, the pile having 40 per cent voids and being of sizes that would pass through a ring 1¾ inches in diameter, mixed with river sand in proportions of ten volumes of the broken stone and four volumes of sand. The pile was 10½ inches in depth, 25 inches wide, 2 feet 5 inches long on top, and 4 feet 6 inches long at the bottom; it was confined on the sides but not on the ends. The load was applied on top of the pile through a 20 by 20 inch bearing plate. The following table shows the loads and settlements. The maximum load was 800,000 pounds and the maximum settlement was 4.7 inches.

Loads and settlements of a pile of broken stone and sand.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
2,550	....	100,000	2.41	488,000	4.13
13,000	0.67	180,000	3.02	640,000	4.43
27,300	1.27	249,700	3.39	8001000	4.69
52,300	1.82	337,600	3.73		

TEST NO. 8.

In this test a cast-iron cylinder was filled with coal culm flushed in with water. A piston was then placed on top of the culm and the whole was allowed to stand on a boiler for two days; the cylinder was then placed in the testing machine and pressure was applied to the piston, which in turn communicated the pressure to the culm. within the cylinder. The inside dimensions of the cylinder were as follows: Diameter, 6⅞ inches; depth, 10⅞ inches. The depth of the culm in the cylinder was 10 inches. The pressure was applied to the piston and the culm was compressed until the settlement reached 2.7 inches under a load of 200,000 pounds. This load corresponds to a pressure of 6,150 pounds per square inch or 443 short tons per square foot. The loads and settlements are given in the following table:

Loads and settlements of wet coal culm confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,100	0.66	55,400	1.82
1,100	0.10	12,100	.76	65,000	1.94
2,100	.19	14,100	.85	75,000	2.04
3,100	.27	16,100	.93	85,400	2.13
4,100	.32	18,100	1.01	95,000	2.21
5,100	.36	20,100	1.07	106,300	2.32
6,100	....	25,100	1.22	124,670	2.40
7,100	.43	30,100	1.34	150,000	2.44
8,100	.58	35,100	1.45	200,000	2.73
9,100	.63	45,000	1.66		

TEST NO. 9.

This test consisted in applying pressure to the piston of a cast-iron cylinder in the same manner as in test No. 8, but the cylinder was filled with broken dry sandstone instead of coal culm. This broken sandstone had 40 per cent voids, and the pieces would all pass through a ring 1¾ inches in diameter. The cylinder was filled to the top, giving a depth of stone of 10 7/16 inches. The maximum load applied was 300,000 pounds, which caused a settlement of 3½ inches, or 9,200 pounds per square inch. As a result of the test, the stone was completely crushed and compressed into the iron cylinder so that it had to be cut out with a chisel. The loads and settlements for this test follow:

Loads and settlements of broken sandstone confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	16,000	1.79	75,000	2.91
2,000	0.46	18,000	1.89	100,000	3.07
4,000	.72	20,000	1.94	125,000	3.18
6,000	1.10	25,000	2.15	150,000	3.28
8,000	1.30	30,000	2.32	175,000	3.35
10,000	1.43	35,000	2.42	225,000	3.51
12,000	1.56	40,000	2.52	275,000	3.55
14,000	1.69	50,000	2.67	300,000	3.56

TEST NO. 12.

This test was similar to test No. 8 except that the cylinder filled with the culm was allowed to stand, with the piston removed, for eight days over a boiler. The culm was 9 inches deep in the cylinder, and the pressure was applied to the piston until the settlement reached 3 inches under a load of 300,000 pounds. This load corresponds to a pressure of 9,200 pounds per square inch. Although the culm had been drying for eight days, there was considerable water in it; the water was squeezed out during the test. The loads and settlements for this test follow.

Loads and settlements of damp culm confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
500	....	20,000	1.216	150,000	2.631
1,000	0.057	30,000	1.501	200,000	2.762
2,000	.175	40,000	1.708	250,000	2.876
5,000	.452	50,000	1.871	300,000	2.999
10,000	.786	75,000	2.168		
15,000	1.025	100,000	2.373		

TEST NO. 13.

This test was exactly similar to test No. 8, except that the cast-iron cylinder was filled with dry Delaware River sand; the sand was placed in the cylinder and settled by shaking until it was flush with the top. The load was then applied to the piston until a maximum pressure of 300,000 pounds, with a corresponding settlement of 3.4 inches, was reached. The table showing loads and settlements follows.

Loads and settlements of dry Delaware River sand confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	20,000	1.22	150,000	2.75
500	0.13	30,000	1.46	175,000	2.89
1,000	.25	40,000	1.66	200,000	3.01
2,000	.41	50,000	1.83	250,000	3.20
5,000	.65	75,000	2.15	300,000	3.35
10,000	.89	100,000	2.39		
15,000	1.07	125,000	2.59		

TEST NO. 10.

This test consisted in applying pressure to the piston of the cylinder in the same manner as in test No. 9; the broken sandstone had 40 per cent voids; the pieces would all pass through a ring $1\frac{3}{4}$ inches in diameter, and all voids were filled with river sand. The cylinder was filled to the top, giving the mixture of stone and sand a depth of $10\frac{7}{16}$ inches. The maximum load applied was 300,000 pounds, or 9,200 pounds per square inch, which corresponded to a settlement of 2.4 inches. As a result of the test the stone was completely crushed and compacted in the iron cylinder. Loads and settlements for the test follow.

Loads and settlements of a mixture of broken sandstone and river sand confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,000	1.01	75,000	1.83
1,000	0.25	15,000	1.16	100,000	1.95
2,000	.46	20,000	1.27	150,000	2.12
4,000	.66	30,000	1.43	200,000	2.25
6,000	.84	40,000	1.55	250,000	2.34
8,000	.95	50,000	1.65	300,000	2.42

TEST NO. 11.

This test consisted in applying a pressure to the piston of the cylinder in the same manner as in test No. 9; but cinders, formed by burning anthracite coal under boilers, were used in the cylinder instead of culm. The cylinder was filled to the top with the cinders, which had 64 per cent voids. The maximum load applied was 300,000 pounds, or 9,200 pounds per square inch, corresponding to a settlement of 5.3 inches. The loads and settlements for this test follow:

Loads and settlements for anthracite-coal cinders confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,000	2.85	100,000	4.74
700	0.45	14,000	3.23	150,000	4.98
1,400	.93	20,000	3.55	200,000	5.14
2,400	1.38	34,100	3.99	250,000	5.25
4,000	1.89	60,000	4.41	300,000	5.33
6,000	2.34				

TEST NO. 14.

Pure sand was flushed into a cylinder. The sand was allowed to dry for a period of 48 hours. The top of the sand was 1⅛ inches below the top of the cylinder.

The following are the results of the test:

Loads and tests of Delaware River sand confined in a cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
650	....	40,000	0.56	160,000	1.39
2,000	0.05	50,000	.67	175,000	1.51
5,000	.12	75,000	.90	200,000	1.60
10,000	[a].21	100,000	1.00	250,000	1.79
20,000	.31	125,000	1.25	300,000	1.93
30,000	.46				

[a] Water appeared on surface of sand.

TEST NO. 15.

A pile of blue coal measures sandstone, in pieces 3 inches to 6 inches square, the pile measuring 20¼ inches wide, 3 feet 3 inches long on the top, and 9 inches deep, voids on top filled with a small quantity of broken Potsdam sandstone for bearing. On the sides the 3 feet 3 inches dimension was confined by 6-inch by 8-inch timbers; the base plate of the machine and the I beams confined the material on the top and bottom. On the ends the material was free to move outward, but in the test there was very little movement at the ends. The loads were applied to the top of the pile in increments, and the maximum load reached was 600,000 pounds.

The following table gives the loads and the settlements corresponding thereto:

Table of loads and settlements.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
3,100	....	80,000	0.81	232,000	1.56
6,000	....	90,000	.88	305,000	1.57
8,000	0.06	100,000	.93	321,700	1.67
10,000	.12	110,000	.95	352,000	1.76
15,000	.18	120,000	1.00	375,000	1.82
20,000	.255	140,000	1.06	395,000	1.89
25,000	.325	162,000	1.15	425,000	1.97
30,000	.375	180,200	1.25	460,000	2.05
41,000	.48	201,500	1.30	500,000	2.10
50,000	.55	286,000	1.38	525,000	2.17
60,000	.62	240,000	1.43	554,000	2.25
70,000	.73	260,000	1.48	600,000	[a] 2.43

[a] This settlement is equivalent to 27 per cent.

Yours, very truly,

FRANK P. McKIBBEN.

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Bulletin 49

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

CITY SMOKE ORDINANCES
AND
SMOKE ABATEMENT

BY

SAMUEL B. FLAGG

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PREFACE.

The Bureau of Mines is endeavoring to ascertain how mineral fuels in which the Government has a direct interest, by ownership or use, can be utilized with highest efficiency. For this reason the bureau has been, and is, carrying on investigations to ascertain the conditions of furnace construction and management that are necessary to insure the smokeless combustion of the different coals that are found in public lands or are purchased for Government ships and power plants.

Another reason for the bureau undertaking these investigations is the need of better furnace management and a more careful selection of fuel at many Government plants. There are Federal buildings in hundreds of cities. The coals available at many of these cities differ greatly in quality, and the furnaces in some of the Federal buildings were not designed for efficient utilization of the cheapest available coal. Hence, some of the boiler plants smoke badly unless fed with low-volatile coal and have caused repeated complaints not only from neighboring property owners who have suffered damage, but from persons endeavoring to create a civic pride in clear air.

In the course of its fuel investigations the bureau has noted the conditions governing fuel consumption in different cities and has studied the attempts made by these cities to abate smoke through the passage of ordinances imposing penalties on smoky stacks. Some results of that study are presented in this report. The most important conclusion reached is that smoke abatement by ordinance can not hope to succeed unless supported by public sentiment and that a smoke ordinance should look to future prevention rather than to immediate prohibition. In other words, strict control of furnace construction offers much greater hope for smoke abatement than desultory imposition of severe penalties on the escape of " dense " or " black " smoke.

CITY SMOKE ORDINANCES AND SMOKE ABATEMENT.

BY SAMUEL B. FLAGG.

INTRODUCTION.

GENERAL INTEREST IN SMOKE ABATEMENT.

Almost from the inception of the fuel-testing work begun by the Government in 1904 the determination of ways and means for burning smokeless fuels from different sections of the United States has been deemed of great importance by the officials in charge of the work. The results of some of the investigations along this line have been published as bulletins[a] of the United States Geological Survey and of the Bureau of Mines. The large demand for these bulletins has indicated that the subject is of much interest to the public.

Since the fuel-testing investigations were begun in 1904, and in some measure because of them, a marked improvement has been made in the smokeless burning of many fuels, and particularly in the burning of bituminous coal. This advance has resulted partly from a desire to improve general power-plant economy, but more largely from a public demand for less smoke. This demand has steadily increased as the public has become better informed of the possibilities of smoke abatement. The demand has been expressed by the action of chambers of commerce and of civic associations and leagues, as well as by the passage and enforcement of smoke ordinances by nearly all of the large cities of the country. In fact, the greatest advance has come in the past, and must come in the future, through the organized effort of the city smoke departments, supplemented by the active cooperation of citizens.

In connection with the fuel investigations conducted by the Bureau of Mines much information has been accumulated as to the smoke-abatement activities in various cities. The essential features of the information are presented in this report, which, it is believed, will be of public interest and benefit, especially to those communities that are just beginning organized effort to abate unnecessary smoke.

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[a] Randall, D. T., The smoke problem at boiler plants, a preliminary report: U. S. Geol. Survey Bull. 334, 1908, 26 pp. (revised and reprinted as Bull. 39, Bureau of Mines); Randall, D. T., and Weeks, H. W., The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants: U. S. Geol. Survey Bull. 373, 1909, 188 pp. (revised and reprinted as Bull. 40, Bureau of Mines).

ACKNOWLEDGMENTS.

The writer takes this opportunity of acknowledging the interest and cooperation of the smoke departments of many cities. He is indebted to H. M. Wilson, engineer in charge of the bureau's testing station at Pittsburgh, Pa., and to others for suggesting questions to be included in the circulars of inquiry, and to O. P. Hood, chief mechanical engineer of the bureau, for helpful criticism of this discussion. In the preparation of the forms of smoke ordinances herein suggested, frequent reference has been made to the report of the Chicago Department of Smoke Inspection, issued in 1911, and also to the Chicago and the Des Moines ordinances. From these sources much material has been taken without substantial change.

FACTORS AFFECTING SMOKE CONDITIONS IN CITIES.

There are probably no two cities in the United States in which the conditions affecting the problem of smoke abatement are even approximately the same. The differences are caused by a number of factors, among which may be mentioned the status of public opinion, the existence or lack of proper smoke ordinances, organization and personnel of smoke departments, topographic and climatic conditions, character of the fuel used for commercial and domestic purposes, nature and extent of the industrial activities, and the volume of railroad and steamboat or steamship traffic.

A strong public sentiment in favor of smoke abatement is almost an absolute necessity if satisfactory results are to be accomplished. If the smoke ordinance is defective or if the organization charged with its enforcement does not see that its provisions are carried out there will be slow progress. Topographic and climatic conditions have their influence upon the location of industrial plants, upon the location of railways and their grades, and upon the quantity of fuel used for different purposes. As to the character of the fuel, it can readily be seen that where anthracite coal, fuel oil, or natural gas is available and can be economically used in any considerable percentage of the furnaces, smokeless combustion in such furnaces can be obtained with relative ease. It is well known, however, that brick kilns, heating and annealing furnaces, puddling furnaces, as well as locomotive and steamboat boilers, are among the most difficult to fire without smoke, so that the proportion of such furnaces to the total number in a city must be taken into account in making comparisons. According to the Chicago smoke department,[a] locomotives produce 43 per cent of all the smoke emitted in Chicago, and the special furnaces are responsible for 12½ per cent.

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[a] Report of the Department of Smoke Inspection, city of Chicago, 1911, pp. 39, 40.

The status of the smoke-abatement work in each of the principal cities is due mainly to the influence of the several factors mentioned. The extent to which any one of these factors is responsible for the existing conditions in a particular city could be estimated only by those thoroughly familiar with every phase of the work in that city, and acquainted in some degree with conditions in other cities as well.

Undoubtedly the greatest improvement in connection with smoke emission has been made in the stationary steam-boiler furnaces, although in some localities the amount of locomotive and steamboat smoke has been greatly reduced. The explanation for this greater improvement in the one class of furnaces lies in the fact that much more is known regarding the proper design of such furnaces, the conditions of their operation, and the limitations of their design are ordinarily not so exacting, and the personal element is more easily controlled. Most of the railroads issue to their enginemen instructions for firing so as to prevent smoke and waste of fuel, and some of the roads maintain their own force of instructors and smoke inspectors. Where such inspectors are detailed and the firemen follow closely the instructions given, a marked reduction in smoke is noted. Ordinarily, more attention is given to passenger locomotives, and to-day the engines for freight service and shunting work produce more smoke than those in passenger service. Another, and one of the most serious phases of the problem of reducing the smoke incident to the operation of railroads, is the elimination of smoke from roundhouses and from engines standing in yards.

Some of the special furnaces have been made more nearly or quite smokeless by the use of gas, fuel oil, or pulverized fuel, but the adoption of these fuels does not guarantee the elimination of smoke; in fact, the writer has seen some furnaces using them that were among the worst offenders. In some cities the difficulty of making the stacks of these special furnaces smokeless has been given consideration, and such stacks have been exempted by the ordinances; in other cities the smoke departments, realizing this difficulty and following a general policy of cooperation with plant owners, have worked with the owners or operators to bring about as much improvement as possible and have brought no suits so long as the operators appeared to be making every effort to comply with the ordinances.

STATUS OF SMOKE-ABATEMENT WORK IN THE UNITED STATES.

With the idea of learning more definitely the status of smoke-abatement work in this country the Bureau of Mines recently sent out circulars of inquiry to the officials and the antismoke organizations of all the principal cities. From the replies to these circulars and from information obtained by personal inspection condensed statements in regard to the existing conditions in some of these cities have been prepared and are given in the following pages.

In studying the data submitted by the smoke inspectors or other officials the cities were divided according to population into three main groups, viz, (1) cities having less than 50,000 inhabitants, (2) cities of 50,000 to 200,000 inhabitants, and (3) cities of over 200,000 inhabitants.

CITIES OF LESS THAN 200,000 INHABITANTS (GROUPS 1 AND 2).

Out of approximately 240 cities in the first group only 12 reported having either a smoke ordinance or an official charged with smoke inspection. From the second group about 60 replies were received, and of the cities represented by them 17 are making more or less vigorous efforts to suppress the nuisance. Of the 17 cities mentioned, the most active are Des Moines, Iowa; Lowell, Mass.; Syracuse, N. Y.; Toledo, Ohio; Richmond, Va.; and Atlanta, Ga. Des Moines has a new and well-drafted ordinance resembling in many respects the Chicago statute, and its citizens seem to have a decided spirit of cooperation. In Richmond, Va., an ordinance was passed prohibiting the use in certain sections of the city without a permit from the city council of any fuel except anthracite coal. This ordinance was afterwards declared unconstitutional. The city of Nashville, Tenn., is at this time considering the passage of an ordinance, the proposed form for which is modeled rather closely after the commendable Chicago and Des Moines ordinances. The reply from one of the cities in the group says that smoke has been found "a nuisance that can not be abated in the city of ———, for the reason of its being a manufacturing city." The fallacy of such a statement is now recognized by a number of the most important manufacturing cities, and in them, in an increasing measure, the smoke nuisance is being intelligently and successfully combated.

CITIES OF OVER 200,000 INHABITANTS (GROUP 3).

Of the 28 cities having over 200,000 population, 5 are making practically no effort toward smoke abatement, but in 3 of these fuel oil is used almost exclusively and the smoke problem is not serious. A statement concerning each of the 28 cities in group 3 follows:

Baltimore, Md.—The Baltimore ordinance prohibits the emission of dense smoke within the city limits for more than six minutes in any one hour. Furnaces used solely in connection with manufacturing or in buildings used exclusively for such purpose are exempt. With the possible exception of the railroad smoke this city has a smoke problem comparatively easy of solution, but progress in that direction has been very slow because of the general public's lack of interest in smoke abatement. This lack of support has probably resulted largely from the mistaken belief held by many people that systematic or organized effort toward the suppression of the smoke nuisance would bring about injury to the commercial interests of the city.

Boston, Mass.—In Massachusetts, as in several other States, there is a State law prohibiting the emission of dense smoke within the corporate limits of cities having more than a given population. The city of Boston and some of the adjacent territory are governed by a special enactment of the State legislature. The Massachusetts Board of Gas and Electric Light Commissioners has general supervision of the enforcement of the enactment, and the board is empowered to appoint a smoke inspector and such deputy inspectors, clerks, and stenographers as are provided for. The expense incurred in connection with the work is prorated among the several municipalities according to their State tax.

The Boston ordinance differs from other statutes in force in that it classifies stacks according to their size and the character of furnaces they serve and specifies increasing restrictions each year until 1913. There is considerable support for the enforcement of the statute and good results are being reported.

Buffalo, N. Y.—Section 1 of the Buffalo smoke ordinance provides as follows:

> It shall not be lawful within the limits of the city of Buffalo for any persons or person, firm or corporation, or any servant, agent, or employee of any person, firm or corporation to permit or allow, or cause to be permitted or allowed, the discharge or escape into the open air of large quantities of smoke, soot, dust, gas, steam or offensive odor, or to permit or allow any smoke, soot * * * to escape in such manner or in such quantities as to cause or have a natural tendency to cause injury, detriment, or annoyance to any persons or person or the public, or to endanger the comforts, repose, health, or safety of any persons or person or the public, or in such manner as to cause or have a natural tendency to cause injury or damage to business or property.

The restrictions of this section are so sweeping in their nature that it is doubted if they would be sustained in the courts. The emission of any smoke at all could be construed a violation of the section, although the intent of the framers of the ordinance probably was to prevent only the emission of dense smoke.

For the enforcement of this ordinance it is provided in section 4 that—

> It shall be the duty of the board of public works to investigate all complaints made to it of a violation of any of the provisions of this ordinance and report the same to the corporation counsel; it shall be the duty of each inspector connected with the bureau of streets of said city, and of all police officers of said city, to immediately report to said board all persons, firms, or corporations guilty of a violation of this ordinance, together with the names and addresses

of all witnesses having knowledge concerning or being in the possession of facts showing such violation; each and every such inspector or police officer shall have the right and authority at all reasonable hours to visit and inspect premises and all machinery, boilers, furnaces * * *.

It might seem from the foregoing that abundant provision had been made for the enforcement of the ordinance. Reports indicate, however, that the ordinance is not observed and that violators are not prosecuted. This condition is rather to be expected than otherwise because of the divided responsibility for the enforcement of the ordinance. In order to carry on successfully the work of smoke abatement in a city of large size certain individuals must be held responsible for the enforcement of the smoke ordinance and for that alone.

Chicago, Ill.—The ordinance passed by the city council of the city of Chicago, in its essential features, provides for certain officials and specifies their duties as follows:

(*a*) A department of smoke inspection, the head of which is known as the smoke inspector.

(*b*) A smoke inspector appointed by the mayor by and with the advice of the city council.

(*c*) That the person so appointed shall be a " mechanical engineer, qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces, and also in the theory and practice of smoke abatement and prevention."

(*d*) A chief assistant smoke inspector to be appointed by the smoke inspector as provided by law.

(*e*) The qualifications of the chief assistant smoke inspector to be the same as for the smoke inspector.

(*f*) As many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided for by the city council.

(*g*) Appointment by the mayor of a smoke-abatement commission of eight members to act as advisers to the mayor in the organization of the smoke department and to the smoke inspector in the conduct of the department.

(*h*) An advisory board of three consulting engineers of recognized standing, who have had the necessary experience to fit them to act as advisors on engineering questions to the commission, the smoke inspector, and the members of the department.

The Chicago ordinance also provides:

(*i*) That no new power plants are to be built or old plants reconstructed until plans and specifications for such work have received the approval of the smoke inspector, and until a permit for such work has been issued.

(*k*) That no new or reconstructed plants shall be used until inspected by the smoke department and found to be properly constructed, and until a certificate has been issued.

(*l*) That permits shall be secured before making any alterations in chimneys or furnaces, provided such alterations affect in any way the prevention of smoke. Minor changes or emergency repairs not involving a change in the method of preventing smoke may be made without a permit. For violation of this provision a fine of $25 for each day upon which the alteration is prosecuted is the penalty.

(*m*) That the emission of dense smoke from any stack, except for a period of six minutes in any one hour during which the fire box is being cleaned or a new fire is being built therein, is a nuisance and may be summarily abated. Penalty for violation of this provision is a fine not less than $10 nor more than $100 for each offense.

(*n*) That the fees for inspecting plans and for examining plants shall be as follows, the fee to include the issuing of a permit or certificate:

For inspecting plans and specifications of new plants and of plants about to be reconstructed	$2.00
For inspecting plans for repairs and alterations	1.00
For examining plants after erection or reconstruction and before its operation and maintenance	3.00

(*o*) That the possession of a permit or certificate issued by the smoke inspector shall not exempt anyone from penalties for violations of the ordinance.

(*p*) That for violation of any of the provisions of the ordinance (except as otherwise stated) the penalty shall be a fine of not less than $25 nor more than $100 for each offense.

(*q*) That the smoke inspector shall keep a complete record of all plans submitted, of all permits issued, of all plants examined, and of all certificates issued.

(*r*) That if any person acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing for the purpose of deceiving or defrauding any person or persons, or for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be fined $100 for each offense.

Although there is to-day in Chicago an immense amount of coal smoke from all sorts of furnaces, there is certainly no other American city that has made such marked progress toward the scientific solution of the smoke problem. This result is due very largely to the fact that smoke abatement has there, more generally than elsewhere, been recognized and attacked as an engineering problem, and greater efforts have been made to obtain cooperation between plant owners and operators and the city officials. As the result of these efforts, for practically every type of boiler, for stoker and for hand-fired operation, there have been developed settings that make possible the attainment of average or even high boiler capacities, while keeping the density of the smoke produced well within that allowed by the ordinance.

The furnace designs developed for hand-fired boilers stand out as possibly the most distinctive feature of the work in Chicago, because of the comparatively little effort that has been put upon the scientific solution of this part of the smoke problem in other cities. The settings include arches, piers, or walls for the purpose of maintaining a sufficiently high temperature and of obtaining the necessary mixing of the air and gases. Provision is usually made for the admission of extra air immediately after firing, and in many installations steam jets are also required instead of entire reliance being placed upon the other mixing devices mentioned. However, one of the principal contributing factors to the lessening of the smoke from these hand-fired plants has been the knowledge of the firemen that their stacks might at any time be watched by an assistant inspector. The greater care in firing that has resulted from this knowledge has, of course, decreased the smoke. The same result will follow in any city when the necessity for such care is once realized.

Cincinnati, Ohio.—At present (May, 1912) Cincinnati is considering the adoption of a revised smoke ordinance. The ordinance in force provides for a method of grading the density of smoke as well as for ways and means of regulating its emission. The escape of dense smoke from any sort of stack, "except for a period of or periods aggregating six minutes in any one hour during which the fire box is being cleaned out or a new fire is being built therein," is declared a nuisance. Any emission in excess of the above is prohibited, and violators are, upon conviction, subject to penalties of increasing severity with the repetition of the offense.

The proposed statute increases the allowable period of dense smoke emission from 6 to 10 minutes in any one hour, and provides that "the careless or negligent emission of dense smoke as above described from a locomotive engine is hereby declared to be a nuisance." The clause just quoted is believed to make the new ordinance weaker than the old and to make more difficult the abatement of locomotive smoke.

The proposed ordinance is also defective in that the assistant chief smoke inspector and the deputy smoke inspectors are required to have certain qualifications essential to the intelligent prosecution of smoke-abatement work, whereas the head of the department is not expressly required to possess them.

The approval of plans for all new boilers and furnace-construction work and of all repair work is now required before the work can proceed. A certificate of inspection must also be obtained from the smoke inspector after completion of the construction work and before the furnace is operated.

Cleveland, Ohio.—The smoke ordinance in Cleveland allows no period of emission of dense smoke, stating simply that the emission of dense black or gray smoke is a nuisance and is prohibited. Inspection of plans for new work is provided for in the ordinance, and the prosecution of such work without a permit from the smoke inspector is prohibited. The city officials have accomplished much in the way of improving conditions, and their efforts have been actively supported and supplemented by the Cleveland Chamber of Commerce, but the rapid growth of industrial plants in and near the city has had a tendency to make the improvement seem less than it really has been. There is still, however, an immense amount of coal smoke that can and will be eliminated if there is no relaxation of efforts toward the accomplishment of this end.

Denver, Colo.—According to Denver's smoke ordinance, the emission "of dense smoke within the corporate limits of the city and county of Denver is * * * declared to be a public nuisance." Violators of this section are punishable by fine, but the ordinance also provides that "in any suit or proceeding under this article it shall be a good defense if the person charged with the violation thereof shall show to the satisfaction of the court trying the case that there is no known practical device, appliance, means, or method by the application of which * * * the emission or discharge of the dense smoke complained of in that proceeding would have been prevented."

The smoke inspector may "require all steam furnaces or other furnaces * * * to be so constructed, or if already constructed to be so altered, as to lessen or diminish and prevent the * * * emission of such dense smoke therefrom, provided that in any suit * * * it shall be a good defense if the person * * * shall show to the satisfaction of the court * * * that such construction or alteration would not appreciably lessen or diminish or prevent the production and emission of dense smoke."

It is also required that any person having charge of the stoking of any boiler or other furnace shall so stoke it that dense smoke shall not be emitted therefrom. This section provides also that it shall be a good defense if the person charged with the violation shall show to the satisfaction of the court that the smoke was emitted without fault on his part.

Detroit, Mich.—The smoke ordinance in force in Detroit at the present time was approved July 29, 1907. Within the past year or two there has been some agitation to have the statute modified in certain respects, but no definite action has yet been taken. The present ordinance prohibits the emission at any time of dense black or gray smoke "from any smokestack or chimney used in connection with any steam boiler, locomotive, or furnace of any description, in any apartment house, building, boat, or any other structure, or in any building used as a factory, or for any purpose of trade, or for any other purpose whatever within the corporate limits of the city of Detroit * * *" Another clause requires that all furnaces shall be so constructed, altered, or equipped as to prevent the emission of such dense black or gray smoke, and all plans for such construction or alteration are subject to the approval of the smoke inspector.

The board of health, to whom the smoke inspector reports, has published and distributed to the engineers and firemen of the city a small pamphlet on smoke abatement, in which are given instructions for firing several different types of furnaces.

The general policy followed in Detroit in the smoke-abatement efforts is one of education, and operators are urged to install mechanical stoking equipment wherever practicable.

Indianapolis, Ind.—The emission of dense smoke from any stack or chimney, except that of a building used as a private residence, is declared to be a nuisance, and is prohibited. The smoke inspector, who is a deputy of the inspector of buildings, is given authority to require all furnaces to be so constructed, or if already constructed to be so altered, as to prevent the emission of dense smoke therefrom. Permits must be obtained from the smoke inspector before new construction, reconstruction, or alteration of boiler or other furnaces can be started.

The Indianapolis ordinance further specifies that when the smoke emission "is owing to the construction of the furnace * * * or other engineering details relating to boiler or furnace construction or connection he (the smoke inspector) shall make statement of the cause of such nuisance and report to the owners or operators as to necessary changes, alterations, or additions, and fixing a limit of time for such changes * * * to be made * * *," this time not to exceed three months. "In the event, however, that it becomes necessary to install stokers, six months shall be given." In cases where the trouble is primarily overloading, or where alterations will not solve the problem and it is necessary to install new equipment, four months shall be given in which to complete the work if tubular boilers are to be installed, and if water-tube boilers are to be put in the time allowance may be increased to nine months.

Jersey City, N. J.—At present (1912) Jersey City has two smoke ordinances, one prohibiting the emission of dense smoke from locomotives and the other relating to the smoke from stationary boilers and furnaces. Two smoke inspectors, appointed by the board of finance and assigned to the law department, are charged with the duty of smoke inspection. There is no State law relative to smoke emission, but efforts are being made to have such a law passed.

The ordinance relating to the emission of smoke from stationary boilers and furnaces states that "it shall be unlawful to permit the emission of dense smoke from any chimney or smokestack connected with any stationary engine, steam boiler, furnace, range, or fireplace within the limits of Jersey City which smoke contains soot or other substance in sufficient quantity to permit the deposit of such soot or other substance on any surface within said limits."

The other smoke ordinance prohibits "the emission of dense smoke from any stack connected with any engine or locomotive within the limits of Jersey City which smoke contains soot or other substance in sufficient quantity to cause injury to health or damage to property within the corporate limits of said city." Another section of this ordinance states that "any owner, lessee, occupant, manager, engineer, or fireman of any engine or locomotive * * * who permits or allows * * * to be emitted from such smokestack dense smoke containing soot or other substance in such quantity as to cause injury to health or damage to property," shall, upon conviction, pay a penalty of $50 for each violation.

Reports from Jersey City state that the city is "not having very much trouble with the operators of stationary plants, the worst offenders * * * being railroads." The validity of the ordinance relating to stationary plants has not been questioned, but the validity of the other statute is now being tested in the courts. In a number of cases the railroads were convicted in the lower courts, but appeals were taken and these cases are now before the State supreme court. One of the points to be decided by the court is whether or not, under the present laws, the governing bodies of cities in New Jersey have power "to the extent of the abatement of the so-called smoke nuisance."

Both of the present smoke ordinances are open to the objection that they require absolutely smokeless operation, if the courts consider as "dense" all smoke that "contains soot or other substance in sufficient quantity to permit the deposit of such soot or other substance on any surface within" the city limits, or "in sufficient quantity to cause * * * damage to property within the corporate limits."

Kansas City, Mo.—The present smoke ordinance in Kansas City, Mo., declares the emission of dense smoke within its corporate limits to be a nuisance and prohibits such emission. The ordinance is considered to have been violated whenever such smoke is emitted from any stack or chimney, except that of a building used exclusively for residence purposes, "provided it shall first be shown to the satisfaction of the court trying the case that there is or are no known practicable device or devices, appliance or appliances, means or method by the application of which to the building, establishment, or premises the emission or discharge of dense smoke from which complaint is made, whereby at reasonable expense prevention can be had." The weak point in the foregoing provision is that the inclusion of the word "reasonable" in the last clause is apt to lead to much controversy.

Another section provides that "No person, firm, or corporation engaged in the business of manufacturing or selling smoke-consuming devices shall attach any said device to any boiler without first obtaining from the health officer a permit therefor, for which the sum of two dollars ($2) shall be paid to the treasurer of Kansas City, and it shall be the duty of said health officer upon the payment of said permit fee to forthwith issue said permit * * *." It is believed that the wording of this section makes it obligatory on the part of the health officer to issue a permit for the installation of any device upon the payment of the permit fee, whether the device is known to be a proven success or a total failure as a means for preventing smoke.

Authority is also given to this same officer to inspect all "steam furnaces carrying thirty (30) pounds of steam or more, except in buildings used for private residence purposes exclusively * * *;" and, if smoke is being emitted, to require these furnaces to be so altered as to prevent the emission of all unnecessary smoke therefrom. It is provided, however, that "in any suit or proceeding for the violation of this section it shall be a good defense if the person charged with the violation thereof shows to the satisfaction of the court * * * that such alterations would not appreciably lessen or diminish or prevent the production and emission of dense smoke." At present there is no inspector, so that little active work can be done.

Los Angeles, Cal.—The almost exclusive use of oil fuel makes the solution of the smoke problem in Los Angeles much easier than in a city in which bituminous coal is generally used. The Los Angeles ordinance establishes a standard of density for smoke which is 19 per cent black, or a density about that of No. 1 of the Ringelmann chart.[a] The emission of smoke of greater density than this standard for more than five minutes in any one hour is prohibited. It should be noted at this point that, although the firing of oil fuel so as to prevent dense smoke is less difficult than similar firing of coal, the Los Angeles specifications as to standard of density and time of emission permissible are much more difficult to comply with than similar specifications in other cities having smoke ordinances. It appears that buildings used for private-residence purposes exclusively are not exempted in Los Angeles as they are in some other places.

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[a] See p. 26.

No provision is made for the inspection of drawings of new installations or for alterations of furnaces. It is specified that no person shall erect or maintain any chimney or smokestack within 50 feet of any window of any adjacent building unless the top of such chimney "shall be higher than every portion of such window * * *."

Louisville, Ky.—In the city of Louisville the emission of "soot, black or dense gray smoke" from any chimney or smokestack is prohibited. The ordinance does not, however, apply to buildings used exclusively for private residence purposes, nor to locomotives attached to regularly scheduled passenger trains entering, leaving, or standing at depots in Louisville, or attached to through freight trains entering or departing from the city.

The inspector of buildings, to whom the smoke inspector reports, is given authority to require that all boilers and furnaces shall be so designed or shall have such "an efficient smoke preventative" attached to them that the provisions of the above paragraph may be complied with. If, in the judgment of the inspector of buildings, it shall be impracticable so to design or to equip locomotives or small stationary or portable boilers, he may require the use of such fuel and such methods of operation as will make possible compliance with the above specifications.

Plans for new construction or for alteration of furnaces are subject to the approval of the inspector of buildings. It is further specified as a duty of this official that "when from personal knowledge or from any other source the inspector or any of his assistants obtains information that any provision of this ordinance has been or is being violated, the inspector of buildings himself or by one of his assistants shall lodge complaint with the city court against any and all who are guilty of said violation." The purpose of the above specification would, it is believed, be better served if the inspector were required to investigate any report of violation that might be communicated to him and to lodge complaint with the city court whenever such violations could be proved.

The ordinance further provides as follows: "The provision of this ordinance shall not apply to any building, establishment, or premises where there is no known practicable device, appliance, means, or method by the application of which to said building, establishment, or premises the emission * * * of dense smoke * * * could have been or can be prevented." This immunity lasts only so long "as there is no known practicable device, appliance, means, or method * * *." In case of a disagreement as to the practicability of any device "an appeal shall lie from the decision of the inspector of buildings to the board of public safety."

Milwaukee, Wis.—A new smoke ordinance passed by the common council of Milwaukee in October, 1911, includes among its provisions that the smoke inspector "shall be appointed by the mayor, subject to confirmation by the common council, and shall hold office for a term of four years * * *." It also specifies that "no person shall be eligible to said office unless he is by trade or profession a steam or mechanical engineer of at least five years in working at said trade or profession."

The section relating to smoke emission states: "To emit or cause or permit to be emitted into the open air within the corporate limits of the city of Milwaukee or within 1 mile therefrom any dense smoke shall be and is hereby prohibited, provided that nothing herein contained shall prohibit the emission of dense smoke not to exceed five minutes in any one hour of the day or night."

A permit must be procured from the smoke inspector before work can be started on the construction or alteration of "any stationary steam plant, boiler, or furnace. * * * All accidents to stationary steam boilers, furnaces, or smoke-preventing devices shall be reported to the smoke inspector in writing, giving the nature of the accident and the time required to repair the same."

The prohibition of dense-smoke emission outside of but within 1 mile of the city limits is made possible because of a State enactment concerning the production of smoke. The latest report of the smoke inspector states that railroad officials are cooperating with the city department and are designating additional inspectors of their own to further reduce the railroad smoke.

Minneapolis, Minn.—The emission of dense smoke from any sort of smokestack or chimney is prohibited in Minneapolis. The city ordinance states that "the use of soft coal in traction engines, switching engines, and locomotive engines in the city of Minneapolis is hereby declared to be a nuisance; and such use of soft coal, other than smokeless coal, in the city of Minneapolis is hereby prohibited."

The railroad-smoke problem is said to have been "pretty well solved as to locomotives," but the roundhouse smoke is said to be troublesome still.

The ordinance has been tested in the courts and was sustained by the State supreme court in 1911.

Newark, N. J.—The one feature of the Newark smoke ordinance that is worthy of special notice is contained in section 1, which states "that it shall be unlawful to permit the emission of dense smoke from any smokestack or chimney connected with any stationary engine, steam boiler, locomotive, * * * which smoke contains soot or other substance in sufficient quantities to permit the deposit of such soot or other substance on any surface within the limits of said city." The incorporation of the last clause in the above sentence weakens the ordinance and makes it difficult of enforcement. Some specification as to what constitutes dense smoke is desirable, but a method of comparison with some such standard as the Ringelmann chart [a] is believed to best answer the purpose.

The smoke inspector may grant immunity to any plant owner or operator for a period of 30 days during which alterations or changes are being made for the purpose of eliminating smoke, provided the plans for such changes are approved by the inspector. The above period may be extended by him if at the expiration of the 30 days the work is not completed and if he is satisfied that the owner or operator is acting in good faith; such extension is not to exceed in all four months from the first approval of said plans. Authority is given to the finance committee of the common council under the same circumstances to still further extend the period of immunity so much "as to them may seem reasonable * * *." The approval of plans for such changes "shall not relieve such owner or owners * * * from liability for violations * * * of this ordinance if such alterations, changes, or device, when completed or installed, fail to prevent the emission of smoke of the kind prohibited by this ordinance."

New Orleans, La.—In New Orleans there is no smoke ordinance, and no smoke-abatement work is being done by the city officials.

New York, N. Y.—The New York smoke ordinance prohibits the emission of dense smoke within the city or on the waters adjacent to and under the jurisdiction of the city from any chimney or stack or any other source and prescribes penalties for violations thereof. In the designing of new work, the city does not attempt to exercise supervision with the idea of preventing the installation of furnaces which are, from the standpoint of smoke prevention, poorly arranged. The result of this laxity, together with the availability of the smaller and cheaper sizes of anthracite, has been slow progress in the development of furnaces suitable to the use of the bituminous coals available in that market. Many plants are continuing the use of anthracite coal, or a mixture of bituminous and anthracite, at a greater fuel cost per unit of evaporation, because of the belief that smoke can not be successfully and economically prevented if soft coal is used.

Philadelphia, Pa.—For determining the density of smoke the smoke ordinance of Philadelphia establishes a standard, and the emission from any stack or chimney of smoke of greater density than this standard is prohibited. The following exceptions to this limitation are quoted from the ordinance:

> *Provided, however*, That it shall not be unlawful to permit or suffer the emission or escape of such smoke of a greater degree of darkness than No. 1

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[a] See p. 26.

scale for a period of not more than five consecutive minutes from any locomotive or river steam craft standing with banked fires or engaged in shifting or for a period of not more than 10 consecutive minutes from any locomotive or steam river craft while its fires may be in process of cleaning or preparing for starting: *And provided further*, That none of the provisions of this ordinance shall apply to a locomotive or locomotives or river steam craft in continuous transit through or across the city or while entering or departing therefrom.

The provisions of this ordinance shall not apply at any time between the hours of 4 o'clock a. m. and 7 o'clock a. m.

The effect of these exception is practically to exempt locomotives and steam river craft from observance of the ordinance.

Pittsburgh, Pa.—A new ordinance passed in October, 1911, by the city council provides for the regulation of smoke emission from all furnaces except mill heating and puddling furnaces and those in private residences. No steam-boiler or other furnace can be constructed within the city until an application for a certificate, accompanied by plans and specifications showing the means of smoke prevention, has been approved by the smoke inspector. It is specified that no discrimination shall be exercised for or against any method for eliminating the smoke; also that the issuance of or the holding of a permit does not exempt anyone from prosecution for violation of the ordinance.

All furnaces except those above mentioned must be so constructed and operated as not to exceed eight minutes' emission of dense gray or black smoke in any one hour, provided, however, that " during the first hour in which a new fire is being kindled in or under a cold boiler or other furnace, excepting in private residences, mill heating furnaces and puddling furnaces, sixty (60) minutes once a day for the first year, forty-five (45) minutes once a day for the second year, and thirty (30) minutes once a day for the third year and each and every year thereafter of dense black or dense gray smoke issuing from the stack or chimney thereof will not be a violation of this ordinance; but, during each succeeding hour that such boiler or other furnace is in service, more than eight (8) minutes of dense black or dense gray smoke issuing from the chimney or stack thereof in any one hour shall be and the same is a violation of this ordinance." Not only is this allowable time of smoking during the period of building fires too liberal, but such a provision makes much more difficult the work of the smoke inspector. In a plant where several boilers are connected to one stack it is possible for such a stack to smoke for as many hours as there are boilers without the ordinance being violated, provided that a new fire is started each hour. It is also necessary for the smoke inspector to go into the plant each time the eight minutes' emission is exceeded to see if a new fire is being started.

The ordinance requires that when the provisions are being violated the smoke inspector shall investigate, shall make complaint to the persons so offending, and, if the cause thereof is unskillful stoking, shall give proper instructions to correct the trouble, at the same time making "complaint to the director of the department of public health against any and all such persons violating this ordinance." If the trouble is due to improper construction of furnace or stack connections, or other engineering details, "he shall make statement of the cause of such offense and report to the owners or operators as to the necessary changes, alterations, or additions to be made." These must be completed within six months. If the installation of additional boiler units or the entire reconstruction of the existing units is necessary, "not more than nine (9) months shall be allowed in which to complete such changes." Notices must be in writing, and at the expiration of the time allowance the chief smoke inspector must investigate and make report to the director of the department of public health as to the condition of the plant, who, if the plant is maintained as an offender against the provisions of the ordinance, may cause suit to be entered, as provided by law, against any and all persons in charge who are violating the ordinance.

The ordinance further provides as follows:

> All accidents to furnaces or smoke-preventing devices in use * * * shall be reported within seventy-two (72) hours to the chief smoke inspector, giving the nature of the accident and the time required to repair the same. Failure to make such report shall constitute a violation of this ordinance.

It is specified that for determining the density of smoke Ringelmann's No. 3 shall be considered dense gray and Ringelmann's No. 4 dense black.[a]

Portland, Oreg.—The city has a section in the general code prohibiting the emission of dense smoke, but has no smoke inspector. No organized or systematic smoke-abatement efforts are being carried on. The need for such work, however, is not great on account of the almost exclusive use of oil fuel.

Providence, R. I.—By an act of the General Assembly of Rhode Island the "emission of dense or thick black or gray smoke" from any smokestack or chimney "for a longer period than five minutes at any one time within any city of the State having a population of 150,000 or more, shall be deemed and is hereby declared to be, a public nuisance: *Provided*, That nothing in the act shall be construed as applied to chimneys of buildings used exclusively for private residences, or to locomotives during the time of starting and feeding fires therein while in roundhouses or roundhouse yards."

The defect of this enactment was pointed out by the mayor of Providence, in a public address given over a year ago, when he said: "Since these measures were adopted an improvement has been noted, but complaints are still being made, and in most instances they appear to be reasonable. Our present law on the subject permits the emission of black smoke for five minutes at one time without limiting the frequency of these periods."

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[a] See p. 26.

Rochester, N. Y.—The Rochester smoke ordinance establishes a color scale about 30 per cent black, to be used in determining the darkness of smoke emitted, and prohibits the emission of smoke of greater density, except as quoted below:

> It is forbidden and hereby declared to be unlawful to suffer or permit the escape of smoke from any fire not in motion or fire banked or in a state of rest, or from any burning or active fire through a stationary stack, flue, or chimney of a color darker than said scale: *Provided, however,* That the provisions of this ordinance shall not apply to the escape of smoke from any stationary stack, flue, or chimney for a period of not to exceed five minutes whenever the successful operation and management of any fire necessarily requires such escape of smoke, but such escape of smoke shall not be permitted or allowed for such period more often than once in four consecutive hours.

Smoke darker than the scale mentioned must not be emitted "from any locomotive or canal steam craft standing with banked fires or engaged in shifting or moving within the city limits, * * * or for a period of more than 10 minutes from any locomotive or canal steam craft whose fires may be in preparation for starting, but such escape of smoke shall not be permitted or allowed for such period of time more often than once in 24 consecutive hours * * *." None of these provisions relating to locomotives or boats applies to a locomotive or canal steam craft in transit through or across the city from some point outside the city, or entering or departing therefrom, if such locomotive or canal steam craft does not stop within the city for five consecutive minutes or for periods amounting to more than five minutes. The provisions of the smoke ordinance do not apply between the hours of 5 a. m. and 7.30 a. m.

San Francisco, Cal.—The almost exclusive use of oil fuel in San Francisco makes possible, under nearly all conditions, the generation of heat or power without the emission of dense smoke. At the present time San Francisco has no smoke ordinance and there is no organized effort toward smoke abatement.

Seattle, Wash.—The conditions in Seattle are practically similar to those at San Francisco, as the use of oil fuel is becoming more and more general.

St. Louis, Mo.—A bill has recently been introduced in the municipal assembly with the idea of making certain changes in the present smoke ordinance, which was approved March 12, 1902. This ordinance prohibits the emission of any dense smoke within the city, but provides that "in any suit or proceeding under this ordinance it shall be a good defense if the person charged with the violation thereof shall show to the satisfaction of the jury or court trying the facts that there is no known practicable device, appliance, means, or method by application of which to his building, establishment, or premises the emission or discharge of the smoke complained of in that proceeding could have been prevented."

A smoke-abatement department was created by the ordinance and for some years the work was carried on by that department. About two years ago the work was transferred and put under the direction of the inspector of boilers and elevators, the smoke-abatement department being abolished. Two civic organizations, the civic league and the women's organization for smoke abatement, are supplementing the work of the city inspectors, the women taking an active part in the efforts to secure a strict enforcement of the ordinance.

St. Paul, Minn.—The St. Paul smoke ordinance simply prohibits the emission of dense smoke from any smokestack or chimney and specifies the penalty for violating the provisions of the ordinance.

Washington, D. C.—The escape of dense black or gray smoke or cinders from any stack or chimney in Washington, except those of buildings used exclusively for private residence purposes, is prohibited. Because of the small number of manufacturing plants in the city, the extensive use of anthracite or low-volatile bituminous coals, and the vigilance of the inspectors, there is little smoke in Washington.

NECESSITY OF SMOKE ORDINANCES IN CITIES.

In the foregoing pages has been given a brief statement concerning the work of smoke abatement in some of the more important cities of the country. As the most active and effective efforts are being made in the cities mentioned, each of which has some form of ordinance to regulate the production and emission of dense smoke, an ordinance of proper form would seem necessary if further progress in smoke abatement is to be made. The time may come when public sentiment against permitting the escape of dense smoke will be so strong that every plant owner or operator will feel obliged to prevent such escape of smoke, regardless of the existence of an ordinance or of his own personal feelings or inclinations. So far as the writer knows, such a condition prevails to-day in no city in the United States. Just as soon as each individual realizes that it is not only his duty but that it will work to his own benefit to cooperate in that which will result in the greatest good to all, just so soon will the necessity for a smoke ordinance disappear. In the meantime, however, or until the present methods of burning bituminous coal are radically changed, such a necessity will exist in those localities where large quantities of such coal are consumed.

THE FUNCTION OF A CITY SMOKE ORDINANCE.

Although the passage of a proper ordinance is not, by any means, the solution of the smoke-abatement problem, it is, however, one of the most important steps, and a clear realization of the function of such a statute is therefore essential.

In order to make easier and more certain its enforcement, the ordinance should state definitely what density of smoke is permissible and what density shall not be emitted. Some practical standard of comparison by which the density of the smoke may be determined should be specified. A few of the cities have adopted for this purpose a piece of glass of a certain color and density, and the ordinances in these cities specify that smoke of darker color or of greater density than that of a certain number of thicknesses of this "standard" glass is prohibited. When this method of comparison is used the observer, by looking through the glass with one eye and through or at the smoke with the other, determines whether the glass or the smoke cuts off the greater per cent of the light from the sky.

Other cities use as a standard a chart made by laying out on a white card black lines of specified width at right angles to each other and with a given spacing. The chart is placed in line with the stack with which it is to be compared and at such a distance from the observer's eye that the ruled-line area appears to be of a uniform shade or color. The smoke observed must not be darker than the chart. A large proportion of the cities simply prohibit the emission of "dense" gray or black smoke and do not further define the word "dense." Obviously, an ordinance so formulated leaves open for argument the question as to what is dense smoke, and conviction for violation will for that reason be more difficult.

One objection to the use of the colored glass as a standard is the necessity of using some special device or some glass that has been tested. Comparatively few people would be supplied with such a device or such glass, whereas anyone could prepare according to proper directions the chart described, or such charts could be printed at small expense and distributed gratuitously or sold for a nominal sum. The Ringelmann smoke chart[a] previously mentioned is extensively used for the purpose of grading the density of smoke and is believed to be the best standard for comparison. The division of this chart into four parts or sections of increasing degrees of density makes possible its use by cities desiring to set different standards for all stacks or various standards for the different classes of furnaces.

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[a] The Ringelmann smoke chart, like the chart standard suggested above, is composed of black-line squares. The Ringelmann chart, however, is divided into four parts or cards, the lines forming the squares being of varying widths on the four cards. Desirable widths and spacings for the lines on each card are given by Professor Ringelmann as follows:

Card 1.—Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Card 2.—Lines 2.3 mm. thick, spaces 7.7 mm. square.

Card 3.—Lines 3.7 mm. thick, spaces 6.3 mm. square.

Card 4.—Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 0, all white, and card 5, all black, are sometimes used, card 0 representing no smoke and card 5 representing smoke 100 per cent dense.

In making observations of smoke proceeding from a chimney the four cards, printed in a horizontal row on one chart, are hung at a point about 50 feet from the observer and as nearly as convenient in line with the chimney. At this distance the lines become invisible, the cards ranging in tint from very light gray to almost black. The observer glances from the smoke coming from the chimney to the cards, determines which card most nearly corresponds with the color of the smoke, and makes a record accordingly, noting the card number and time of observation. The observations are repeated at one-fourth or one-half minute intervals. From these records the smoke density may be determined for each hour or for each day.

Copies of this chart may be obtained from the Bureau of Mines.

In fixing the density of smoke that is to be permitted, the requirements should be representative of the best practice; the standard set should not be an impossible nor an impracticable one, neither should it represent ordinary or poor practice. Since the prime object in making these requirements is to bring about an improvement, the standard should be an improvement over the existing local average, in the determination of which the local conditions must be given thorough consideration. In order that the requirements so fixed may be observed, sufficient provision must, of course, be made for penalizing those who refuse to do so.

Another and larger function of the ordinance is to provide ways and means for keeping existing plants within the requirements and for preventing in the future as far as possible the installation of improperly designed furnace equipment. Obviously, to accomplish the purpose just mentioned there must be persistent and systematic effort. In other words, organization is necessary, and the ordinance should specify how the work is to be organized, and also the necessary qualifications of those who are to be appointed to carry it on. Satisfactory progress will seldom be made unless the organization is such that certain officials or employees give their entire attention to the smoke-abatement work and are held responsible for the results produced.

If the installation of improperly designed furnaces is prevented, the policing duties of the smoke inspectors will eventually be reduced to a minimum. The advisability of making this sort of provision is clearly shown in nearly any one of the cities where this protective work is not done, by the fact that some of the newest plants have been so constructed that dense smoke is emitted a large part of the time, even though the firing may be done with a fair degree of care and intelligence. The smoke ordinance should therefore require that plans and specifications for all construction work on furnaces be submitted to the smoke inspector and be approved by him before work is started. If this protective feature is to be included, the smoke inspector must be an engineer, qualified by technical training and experience for the duties of the office, and the ordinance should specify that these qualifications are required.

It may at first appear that if the smoke inspector is to be given the power to decide what furnaces may be installed and what shall be forbidden, the owners or operators should not be held liable for smoke emitted from furnaces constructed according to approved plans. The adoption of any such provision for immunity, however, would release the operator from all responsibility for the way in which the fires were handled. Practically every furnace will produce smoke if improperly handled; hence the operator must be held responsible for the way in which the stoking is done. The inspection of drawings is provided for, not with the idea that the smoke inspector shall design plants for the owners, but rather that he may withhold his approval of plans for work that is known to be improperly designed.

ESSENTIAL FEATURES OF A SMOKE ORDINANCE.

If the number of defective or ineffective smoke ordinances, the number of revisions of this class of city statutes, or the number of inquiries received by the Bureau of Mines may be considered as indicative, there is a need for more technically advised legislation and for more information along these lines. The exact form that the ordinance for any particular city should take can be decided upon only after a study has been made of the existing local conditions. Experience has shown, however, that certain features are desirable and that certain others are undesirable, and in the comment on the city ordinances in the preceding portion of this paper some of both the desirable and the undesirable features are noted. There are presented in the following pages two specimen forms for such enactments, one adapted to the average conditions in a city of, say, 200,000 population or over and the other for a city of smaller size. It is not the writer's idea that these forms should be used without change, but they are offered as representing what is believed to be the best practice to-day. If, as such, they prove valuable to city councils, chambers of commerce, or other city organizations as guides for framing new ordinances, they will have served their purpose.

LARGE CITY.

A form of ordinance proposed for a city of over 200,000 inhabitants is as follows:

Proposed form of smoke ordinance for a large city.

An ordinance providing for smoke inspection and abatement in the city of ———.

The city council of the city of ——— do ordain as follows:

SECTION 1. There is hereby created a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 2. The smoke inspector shall be appointed by the mayor by and with the advice of the city council and shall perform the duties of his office until removed from office or until his successor is appointed.

SEC. 3. The person so appointed shall be a mechanical engineer qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces; also in the theory and practice of smoke abatement and prevention.

SEC. 4. The smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of ———— in the sum of ——— thousand dollars ($———) with sureties approved by the mayor and conditioned upon the faithful performance of his duties.

SEC. 5. The salary of the smoke inspector shall be ——— dollars ($———) per annum.

SEC. 6. There is hereby created the office of assistant chief smoke inspector, who shall be appointed by the smoke inspector as provided by law.

SEC. 7. The person so appointed shall possess the same qualifications as those specified for the smoke inspector.

SEC. 8. The assistant chief smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of ———— in the sum of ——— dollars ($———) with sureties approved by the mayor and conditioned upon the faithful performance of his duties.

SEC. 9. The salary of the assistant chief smoke inspector shall be ——— dollars ($———) per annum.

SEC. 10. There shall be as many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided by the city council, their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector, as provided by law.

SEC. 11. The city council shall appoint a smoke-abatement commission composed of seven representative citizens who shall act as advisers to the mayor and to the smoke inspector upon matters pertaining to the organization or the conduct of the department, or both. The smoke inspector shall at all times receive and place and keep on file all suggestions, recommendations, advice, or other communications that may be submitted to him in writing by the smoke-abatement commission.

SEC. 12. The smoke-abatement commission may name an advisory board of mechanical engineers, which shall consist of three consulting engineers of recognized ability and integrity, who have had experience in the installation and operation of steam power and heating plants. This board shall act as advisers on engineering questions to the smoke-abatement commission, to the smoke inspector, and to the members of the department. Meetings of the advisory board may be called at any time by the smoke-abatement commission or by the smoke inspector. Members of the advisory board shall receive for their services the sum of ——— dollars ($—) for each regularly called meeting attended.

SEC. 13. No work shall be done upon the erection of any new plant, or on the reconstruction of any old plant for the production of power or heat, or on the erection or reconstruction of any part thereof, except as hereinafter specified, until plans and specifications for such erection or reconstruction shall have been submitted to and approved by the smoke inspector, and a permit issued by him for the prosecution of such work. These plans and specifications shall show not only the nature and extent of the proposed construction work, but also the amount of power or heat to be supplied by such plant and all appurtenances thereto, including all provisions made for the purpose of obtaining complete combustion of the fuel to be used and for the purpose of preventing smoke. Said plans and specifications shall also contain a statement of the kind of fuel to be used, including the commercial size of coal when such fuel is specified; said plans and specifications shall also show that the room or apartment in which such plant is to be located is provided with doors, windows, or other means of ventilation sufficient to prevent the temperature of any room or apartment wherein such steam plant or apparatus is to be used from rising to a point higher than 120° Fahrenheit, and sufficient also to provide that the atmosphere of any such room or apartment may be entirely renewed every ten minutes. Upon the approval of said plans and specifications, a duplicate set of which shall be left on file in the smoke inspector's office, and upon payment of the fees as hereinafter provided, a permit shall be issued for the erection or reconstruction of such plant. Upon the issuance of such permit the smoke inspector shall then notify the superintendent of building inspection, whose duty it shall then be to see that the work for which the permit has been granted is carried out in accordance with the plans and specifications, with especial reference to the amount of space used, the size and construction of the chimney or chimneys used, the provisions for the prevention of smoke, and the provisions for ventilation and for the proper temperature in the engine and boiler rooms.

SEC. 14. It shall be unlawful for any person to use any new or reconstructed plant for the production of heat or power, until he shall have first procured from the smoke inspector a certificate stating that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke will be emitted from the chimney connected to the furnace or firebox.

SEC. 15. No owner or operator shall alter or repair any plant for the production of heat or power, or any part thereof, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and obtaining a permit therefor; provided, however, that minor necessary or emergency repairs that do not increase the capacity of such plant, or that do not involve any alterations in the method or efficiency of smoke prevention may be made by or under the engineer in charge of said plant without a permit. Any person who shall violate this section shall be liable to a fine of $25 for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 16. The fees for the inspection of plans and specifications, for the issuing of permits, and for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans of new plants and of plants about to be reconstructed, $2.

For inspecting plans for repairs and alterations, $1.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $2.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate, in case such permit or certificate is granted.

SEC. 17. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, or steam tug for a period of more than one minute, except for a period or periods aggregating not to exceed 10 minutes in any one hour during which period or periods the firebox is being cleaned or a new fire is being built therein, is hereby declared a nuisance: *Provided*, That the fire engines or the fire boats of the city fire department, or both of them, shall be exempt from these restrictions.

The emission of dense smoke within the city from the smokestack of any steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, except for a period or periods aggregating not to exceed six minutes in any one hour during which period or periods the firebox is being cleaned or a new fire is being built therein, is hereby declared a nuisance.

Any nuisance such as the above-specified may be summarily abated by the smoke inspector, or by anyone whom he may duly authorize for the purpose, and such abatement may be in addition to the fine hereinafter provided.

Any person or persons, or corporation, owning, operating, or in charge or control of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke within the city, in contravention of the provisions of this section, from the smokestack of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestock or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, shall be deemed guilty of a violation of the ordinance, and upon conviction thereof shall be fined not less than ten dollars ($10) nor more than one hundred dollars ($100) for each offense; and each day of such emission of dense smoke shall constitute a separate offense.

For the purpose of grading the density of smoke, the Ringelmann smoke chart, as published and used by the Federal Bureau of Mines, shall be the standard of comparison. Smoke shall be considered "dense" when it is of a greater density than No. 3 of the chart.

Sec. 18. The provisions of sections 13, 14, 15, and 17 shall not apply to detached private residences, nor to buildings used exclusively for private residence purposes, in which the number of families occupying apartments shall be less than five.

Sec. 19. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of ———.

The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction of, or any permit for the alteration or repair of any plant or chimney connected with a plant shall not be held to exempt any person or corporation to whom such permit or certificate has been issued or delivered, or who is in possession of any such permit or certificate, from prosecution on account of the emission or issuance of dense smoke caused or permitted by such person or corporation.

Sec. 20. Any person who shall violate any of the provisions of this ordinance, except as otherwise provided, shall be fined not less than ——— dollars ($—) nor more than ——— dollars ($—) for each offense.

Sec. 21. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the members of the department. The smoke inspector shall have charge of such instruments, books, paper, and equipment, and shall deliver the same to his successor in office.

Sec. 22. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted, of all permits issued, of all examinations of plants made by members of the department, and of all certificates issued. He shall also cause to be kept a record of all stacks observed and of the smoke observations for any stack that is found to exceed the allowable time limit for dense smoke.

Sec. 23. The smoke inspector shall make an annual report of the work of his department to the mayor and to the city council on or before ————, and at such other times as he may be required by the city council.

Sec. 24. If any person acting on behalf of the city under the provisions of the ordinance shall take or receive any money or any valuable thing for the purpose of deceiving any person or persons, or for the purpose of favoring any person or persons, he shall be fined ——— dollars ($——) for each offense and shall be dismissed from the service, and any bond he may have made shall be for-

feited; or if the inspector shall issue any certificate of inspection before the department shall have thoroughly examined and inspected the furnace, device, or apparatus as certified, he shall be fined ——— dollars ($——) for each offense.

MEDIUM-SIZED CITY.

It is recognized that the smaller cities can not maintain as extensive an organization to carry on the smoke-abatement work, and that it is usually not practicable to make regulations so stringent therein as is advisable in the larger cities. In other words, the smaller city must adopt somewhat different methods in this work than are practicable for the larger city. A form of ordinance suitable for the average conditions in cities of 50,000 to 200,000 inhabitants has therefore been drafted and is as follows:

Proposed form of smoke ordinance for a medium-sized city.

An ordinance providing for smoke inspection and abatement in the city of ————.

The city council of the city of ———— do ordain as follows:

SECTION 1. There is hereby created the office of smoke inspector, the compensation and duties connected therewith to be as hereinafter specified.

SEC. 2. The smoke inspector shall be appointed by the mayor, by and with the advice of the city council, and shall perform the duties of his office until removed from office or until his successor is appointed.

SEC. 3. The person so appointed shall be an engineer qualified by training and experience in the theory and practice of the construction of steam boilers and furnaces, also in the theory and practice of smoke abatement and prevention.

SEC. 4. The salary of the smoke inspector shall be ——— dollars ($———) per annum.

SEC. 5. There shall be as many deputy smoke inspectors, assistant smoke inspectors, clerks, and stenographers as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector as provided by law (or by the mayor, by and with the advice of the city council).

SEC. 6. The city council shall appoint a citizens' smoke-abatement committee composed of seven (7) representative members, who shall act as advisors to the mayor and to the smoke inspector upon matters pertaining to the organization or the conduct of the smoke-abatement work, or both. The smoke inspector shall at all times receive and place and keep on file all suggestions, recommendations, advice, or other communications that may be submitted to him in writing by the said committee.

SEC. 7. The citizens' smoke-abatement committee may procure the services of a consulting mechanical engineer of recognized ability who has had experience in the installation and operation of steam power and heating plants, and particularly in the prevention of smoke in such plants, to advise the smoke inspector and the committee upon engineering problems in connection with the smoke-abatement work whenever such advice is required; provided, however, that the total expense incurred for such consulting advice shall not exceed the sum allowed for such purpose by the city council.

SEC. 8. It shall be unlawful for the owner, lessee, or operator of any existing plant, or of any plant about to be constructed, for the production of power or heat, to proceed with the construction, reconstruction or alteration of such plant heat, to proceed with the construction, reconstruction, or alteration of such plant until plans and specifications for such work shall have been submitted to the smoke inspector, approved by him, and a permit for such work issued. These plans and specifications shall show the nature and extent of the work to be done, including the provision that is to be made for the prevention of smoke. If, in the opinion of the smoke inspector, the provision made for the prevention of smoke is not sufficient to enable the owner or lessee to operate the plant under the conditions that will be imposed upon it without violating the provisions of this ordinance, the approval of such plans shall be withheld. Upon the approval of such plans a duplicate copy shall be left with the smoke inspector, who shall then notify the building inspector, and it shall be the duty of said building inspector to see that the work is done in accordance with the plans and specifications. The foregoing provisions of this section shall not apply to the steam plants in buildings used exclusively for private residence purposes in which the number of families occupying apartments shall be less than five, nor to minor necessary or emergency alterations or repairs in any other plants, which alterations or repairs do not increase the capacity of said plants, or which do not involve any substantial alteration in structure, and which do not involve any alteration in the method or efficiency of smoke prevention.

Any person who shall violate this section shall be liable to a fine of twenty-five dollars ($25) for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 9. A fee of one dollar ($1) shall be charged for the inspection of plans and specifications for the erection, reconstruction, or alteration of any plant, this fee to include the issuing of a permit, in case such permit is granted.

SEC. 10. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, or steam tug for a period of more than seventy-five (75) seconds, except for a period or periods aggregating not to exceed 12 minutes in any one hour, during which period or periods the firebox is being cleaned or a new fire being built therein, is hereby declared a nuisance: *Provided*, That the fire engines or fire boats of the city fire department, or both of them, shall be exempt from these restrictions.

The emission of dense smoke within the city from the smokestack of any steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, except for a period or periods aggregating not to exceed nine minutes in any one hour, during which period or periods the fire box is being cleaned or a new fire is being built therein, is hereby declared a nuisance.

Any nuisance such as the above specified may be summarily abated by the smoke inspector, or by anyone whom he may duly authorize for the purpose, and such abatement may be in addition to the fine hereinafter provided.

Any person or persons, or corporation owning, operating, or in charge or control of any locomotive, steamboat, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke within the city, in contravention of the provisions of this section, from the smokestack of any such locomotive, steamboat, steam tug, steam roller, steam pile driver, steam derrick, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, shall be deemed guilty of a violation of this ordinance, and upon conviction thereof shall be fined not less than ten dollars ($10) or more than one hundred dollars ($100) for each offense; and each day of such emission of dense smoke shall constitute a separate offense.

For the purpose of grading the density of smoke the Ringelmann smoke chart, as published and used by the Federal Bureau of Mines, shall be the standard of comparison. Smoke shall be considered "dense" when it is of greater density than No. 3 of the chart.

The provisions of this section shall not apply to detached private residences, nor to buildings used exclusively for private residence purposes, in which the number of families occupying apartments shall be less than five.

SEC. 11. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of ———————.

The issuance and the delivery by the smoke inspector of any permit for the construction, reconstruction, alteration, or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense smoke caused or permitted by such person or corporation.

SEC. 12. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper prosecution of the smoke-abatement work. The smoke inspector shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 13. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted and of all permits issued. He shall also cause to be kept a record of all stacks observed and of the smoke observations from any stack that is found to exceed the allowable time limit for dense smoke.

SEC. 14. The smoke inspector shall make a report of his work or the work done under his direction to the mayor and city council annually, on or before ———————, and at other times as often as required by the city council.

SEC. 15. If any person acting on behalf of the city under the provisions of this ordinance shall take or receive any money or any valuable thing for the purpose of favoring any person or persons, he shall be fined ——— dollars ($———) for each offense and shall be dismissed from the service; or if the inspector shall issue any permit as mentioned in section 8 of this ordinance, without thoroughly examining the plans and specifications for the work for which the permit is issued, he shall be fined ——— dollars ($———) for each offense.

SMALL CITY.

The problem in the city of, say, 20,000 population will usually require a different method of attack than has been outlined for either the large or the medium-sized city. A small city has comparatively few new boiler plants, reconstructions, or alterations in the course of a year, so that the policing phase becomes of major importance. However, the small city ought to protect itself and its manufacturers from the installation of improperly designed furnaces and thereby save heavy expenditures for reconstruction in later years. The board of trade or a similar civic organization of such a city can authorize a committee to obtain information concerning furnace designs or methods of operation developed in other cities, or to inform themselves so that they may be able to direct those interested to competent advisors on the subject of smoke prevention. With a strong public sentiment to supplement its efforts such a civic organization should be able to accomplish much good in the smaller cities that can afford no organized municipal effort toward smoke abatement.

ENFORCEMENT OF SMOKE ORDINANCES.

Undoubtedly, the chief reason why our cities have not made more rapid progress toward smoke abatement has been the failure of those intrusted with the enforcement of the smoke ordinances properly to perform their duties. In many cities where there are ordinances prohibiting or restricting the emission of dense smoke, little report is ever heard of any effort to enforce compliance with their provisions. Nevertheless, one of the first arguments raised by those who are opposing the enactment of such legislation in any city is that they will be continually annoyed by an overbearing inspector. If, as is usually the case, there appears to be laxity in enforcing the ordinance, blame ordinarily attaches to the smoke inspector, whereas to others may belong the greater share of responsibility. It is believed that frequently the real trouble lies in the fact that wrong methods of enforcement are adopted.

Public sentiment is just as necessary for the successful enforcement of smoke ordinances as for the enforcement of any other class of laws or ordinances. Compliance with such enactments can be had and will be demanded by public officials only when required by public opinion, but it is essential for the accomplishment of the best results that the force of such opinion be used in the most effective manner—it should be manifested in constructive effort and not in mere faultfinding. A few cities have considered this matter of such importance that they have provided in their smoke ordinances for stimulating and making the best use of these constructive activities by having a smoke-abatement committee or commission composed of representative citizens to advise with the mayor and the inspector. If the members of such a committee are carefully selected their cooperation should enable the city department to accomplish much more than would otherwise be possible. The committee will, if so selected, act as a balance wheel for the department by preventing inactivity or overactivity.

In this connection the value of the advice of such a committee in assisting the inspector to determine the proper policy to be followed in any particular instance or under any given conditions should not be overlooked. Furthermore, the announcement to the offender of the procedure proposed will frequently be more agreeably received from the chairman or other members of the committee than from the inspector. The prevention of dense smoke in some plants may be possible only after radical changes are made, and in such a case the owner or operator will usually be more inclined to yield to the urging of the committee than he would to that of a city official. The more the plant owners and operators feel that there is a spirit of cooperation being manifested toward them the easier can compliance with the ordinance be obtained.

At the same time, however, firmness and impartiality in carrying out the spirit of the law are equally essential. Promises and excuses are easily made, and some owners are inclined to stave off for as long a time as possible the alterations, reconstruction, or extra attention necessary to enable them to obey the law. The imposing of a fine for excessive smoke will usually have the desired effect on such offenders, but recourse to the courts should be had only when argument and persuasion prove futile.

If the city is large enough to be able to employ a technically trained expert as smoke inspector and to provide for expert consulting advice for him or for the smoke-abatement committee or commission, money will probably be saved to the business interests of the city and more rapid progress made in the elimination of smoke by so doing. Smaller cities that are unable to appropriate sufficient funds for such a course may, in a measure, accomplish the same end by furnishing to plant owners, through their smoke-abatement committees or their chambers of commerce or boards of trade, information relative to, and possibly drawings of, satisfactory installations of any particular type of boiler. Through these same channels they may supply the names of engineers who are capable of advising the owner on difficult engineering problems that may be involved in the building, reconstructing, or altering of plants.

The important point is that the plant owner or operator shall realize the necessity of considering smoke prevention whenever furnace-construction work is to be done, and shall thus be saved the expense of tearing out and reconstructing such furnaces.

CONCLUSION.

It is not intended that the reader will gain from a perusal of the preceding pages the impression that the abatement of coal smoke in any city is a simple problem, or that it can be accomplished in a short time. The effort has rather been to point out wherein some of the efforts toward this end have been misdirected and to indicate what are believed to be better methods of attack. The real reason that more has not been accomplished up to the present time in many of our cities is that, through ignorance or indifference, money and efforts have been wrongly applied. The complete elimination of the smoke nuisance will not be possible in such cities until improved and radically different methods of utilizing the fuel are adopted. With properly designed and well-operated furnaces a great reduction in the amount of smoke is to-day not only possible but is necessary.

APPENDIX.

For the information of persons who wish to know the exact phraseology of some of the smoke-abatement ordinances mentioned in this bulletin, especially of those ordinances that contain features of particular interest, the smoke-abatement ordinances of the cities of Chicago, Pittsburgh, Des Moines, Milwaukee, and Los Angeles are printed at length, as well as the State act that applies to the city of Boston.

The Chicago ordinance is perhaps the most comprehensive and most complete of those in effect in the large cities of the United States. Its requirements apply particularly to the needs of a great industrial center where coals high in volatile matter are the chief available fuel. The ordinance is as follows:

Be it ordained by the city council of the city of Chicago:

SECTION 1. There is hereby established a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 2. The smoke inspector shall be appointed by the mayor by and with the advice of the city council.

SEC. 3. The person so appointed shall be a mechanical engineer, qualified by technical training and experience in the theory and practice of the construction and operation of steam boilers and furnaces, and also in the theory and practice of smoke abatement and prevention.

SEC. 4. The smoke inspector, before entering upon the duties of his office, shall execute a bond to the city of Chicago in the sum of $10,000, with sureties to be approved by the mayor, conditioned upon the faithful performance of the duties of his office.

SEC. 5. The salary of the smoke inspector shall be $4,000 per annum.

SEC. 6. There is hereby created the office of chief assistant smoke inspector, who shall be appointed by the smoke inspector as provided by law.

SEC. 7. The qualifications of the chief assistant smoke inspector shall be the same as the qualifications herein provided for the smoke inspector.

SEC. 8. The chief assistant smoke inspector shall, before entering upon the duties of his office, execute a bond to the city of Chicago in the sum of $5,000, with sureties to be approved by the mayor, conditioned upon the faithful performance of the duties of his office.

SEC. 9. The salary of the chief assistant smoke inspector shall be $3,000 per annum.

SEC. 10. There shall be as many deputy smoke inspectors as shall be provided for by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 11. There shall be as many assistant smoke inspectors as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 12. There shall be as many clerks and stenographers assigned to this department as shall be provided by the city council; their compensation shall be fixed by the city council, and they shall be appointed by the smoke inspector in the manner provided by law.

SEC. 13. The mayor may in his discretion appoint a smoke-abatement commission composed of eight members, who shall act as advisers to the mayor in the organization of the department and as advisers to the smoke inspector in the conduct of the department. The smoke inspector shall at all times receive, place, and keep on file in his office any suggestion, recommendation, advice, or other communication which may be presented to him in writing by the smoke-abatement commission. The smoke-abatement commission may name an advisory board of mechanical engineers which shall consist of three consulting engineers of recognized ability and integrity, who have had experience in the installation and conduct of power and heating plants. This board shall act as advisers on engineering questions to the smoke-abatement commission and to the smoke inspector and to the members of the department. Meetings of the advisory board of mechanical engineers may be called at any time either by the smoke-abatement commission or by the smoke inspector. Members of the advisory board of mechanical engineers shall receive as their compensation the sum of $10 for each member for each regularly called meeting attended.

SEC. 14. No new plants or any reconstruction of any old plants for producing power and heat, or either of them, or any new chimney connected with a steam plant shall be erected or maintained in the city until plans and specifications of the same have been filed in the office of and approved by the smoke inspector and a permit issued by him for such erection, reconstruction, or maintenance. Plans and specifications to be filed with the smoke inspector shall show the amount of work and the amount of heating to be done by such plant and all appurtenances thereto, including all provisions made for the purpose of securing complete combustion of the fuel to be used and for the purpose of preventing smoke; said plans and specifications shall also contain a statement of the kind of fuel proposed to be used, and said plans and specifications shall also show that the room or apartment in which such plant shall be located is provided with doors, windows, air shafts, fans, and other means of ventilation sufficient to prevent the temperature of such room, apartment, basement, or other portion of such building wherein such steam plant or apparatus is to be used from rising to a point higher than 120° F., and sufficient also to provide that the atmosphere of any such apartment wherein such apparatus may be located may be entirely renewed every 10 minutes. Upon the approval of such plans and specifications, a duplicate set of which shall be left on file in said office, and upon the payment of the fees as hereinafter provided, the smoke inspector shall issue a permit for the reconstruction, erection, or maintenance of such plant. As soon as the smoke inspector has examined the plans and specifications submitted and has issued a permit as above provided, he shall then notify the commissioner of buildings to see that the execution of the work permitted is carried out in conformity with the plans and specifications, with special reference to the amount of space used, the size and construction of the chimney or chimneys used, the provisions for the prevention of smoke, and the provisions for ventilation, and for the proper temperature in the engine and boiler rooms.

SEC. 15. It shall be unlawful for any person to use any new or reconstructed plant for the production and generation of heat and power, or either of them, until he shall have first procured a certificate from the smoke inspector that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke shall be emitted from the chimney connected with the furnace or fire box.

SEC. 16. No owner shall alter or repair any chimney or any old furnace or device, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and securing a permit therefor: *Provided, however,* That minor necessary or emergency repairs which do not increase the capacity of such plant or which do not involve any substantial alteration in structure, and which do not involve any alteration in the method or efficiency of smoke prevention, may be made by or under the engineer in charge of said plant without a permit. Any person who shall violate this section shall be liable to a fine of $25 for each day upon which he shall prosecute such alteration, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 17. The emission of dense smoke within the city from the smokestack of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises, excepting for a period of six minutes in any one hour, during which the fire box is being cleaned out or a new fire being built therein, is hereby declared to be a nuisance, and may be summarily abated by the smoke inspector, or by anyone whom he may duly authorize for such purpose. Such abatement may be in addition to the fine hereinafter provided. Any person or persons, or corporation, owning, operating, or in charge or control of any locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke, within the city, from the smokestack or chimney of any such locomotive, steamboat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or from the smokestack or chimney of any building or premises so owned, controlled, or in charge of him, her, or them, except for a period of six minutes in any one hour, during which the fire box is being cleaned out or a new fire built therein, shall be deemed guilty of a violation of this ordinance, and upon conviction thereof shall be fined not less than $10 nor more than $100 for each offense, and each day of such emission of dense smoke shall constitute a separate offense.

SEC. 18. The fees for the inspection of plans and issuing of permits for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans of new plants and plants about to be reconstructed, $2.

For inspecting plans for repairs and alterations, $1.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $3.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate, in case such permit or certificate is granted.

The smoke inspector may, and he is hereby, directed and instructed to remit all inspection or examination fees charged, or that hereafter may be charged, against any and all charitable, religious, and educational institutions when the furnace or other device or apparatus inspected is located in or upon premises used and occupied exclusively by such charitable, religious, or educational institutions: *Provided,* That such charitable, religious, or educational institution is not conducted or carried on for private gain or profit: *And provided further,* That the smoke inspector may require every application for the remission of such fees to be verified by the affidavit of one or more taxpayers of the city.

SEC. 19. Prosecutions for all violations of this ordinance shall be instituted by the smoke inspector and shall be prosecuted in the name of the city of Chicago.

The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction, or any permit for the alteration or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense smoke caused or permitted by any such person or corporation.

SEC. 20. Any person who shall violate any of the provisions of this ordinance (except as is herein otherwise provided) shall be fined not less than $25 nor more than $100 for each offense.

SEC. 21. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the members of the department. The smoke inspector shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 22. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted and of all permits issued and of all examinations of plants made by members of the department and also of all certificates issued.

SEC. 23. The smoke inspector shall make a report of the work of his department to the mayor and city council annually, on or before the 1st day of February, and at other times as often as required by the city council.

SEC. 24. If any person acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing for the purpose of deceiving or defrauding any person or persons, or for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be fined $100 for each offense.

SEC. 25. Chapter LXIV of the Revised Municipal Code of Chicago of 1905, as amended, so far only as said chapter refers to smoke inspection, is hereby repealed, and the position of chief smoke inspector created by said chapter is hereby abolished.

SEC. 26. This ordinance shall take effect on and after its passage and publication.

The Pittsburgh ordinance applies especially to a large manufacturing city in which many metallurgical plants complicate the problem of smoke abatement. The ordinance, which became effective in October, 1911, reads as follows:

SECTION 1. *Be it ordained and enacted by the city of Pittsburgh, in council assembled, and it is hereby ordained and enacted by the authority of the same,* That no steam-boiler furnace or other furnace, excepting in private residences, mill-heating furnaces, and puddling furnaces, shall be constructed within the corporate limits of the city of Pittsburgh until the owner, agent, or lessee shall first make written application at the office of the chief smoke inspector for a certificate for that purpose and shall furnish a written statement and drawings of the style and dimensions of such boiler or furnace, the height and size of stack or chimney, and the method or device for preventing the emission of dense black or dense gray smoke therefrom for more than eight (8) minutes in any one hour, and the chief smoke inspecor's approval has been obtained: *Provided, however,* That no discrimination shall be exercised for or against any method, including hand firing, which will and does now prevent the emission of dense black or dense gray smoke except for eight (8) minutes in any one hour.

SEC. 2. Every boiler furnace or other furnace used within the corporate limits of the city of Pittsburgh, excepting in private residences, mill-heating furnaces, and puddling furnaces, in which bituminous coal is burned as fuel, shall be so constructed or altered as to prevent the production and emission of dense black or dense gray smoke therefrom, except for eight (8) minutes in any one hour; and no person or persons, associations, or corporation being the owner or lessee, or having control of any such steam boiler or other furnace, shall use or allow the use of any steam boiler or other furnace which shall not be so constructed, or if already constructed at the time of the passage of this ordinance, which shall not be so altered, or the method of stoking be so regulated as to prevent the emission of dense black or dense gray smoke for more than eight (8) minutes in any one hour.

SEC. 3. The issuance and delivery by the smoke inspector of any permit or certificate for the construction or reconstruction, or any permit for the alteration or repair of any plant or chimney connected with a plant, shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered, or who is in possession of any such permit, from prosecution on account of the emission or issuance of dense black or dense gray smoke caused or permitted by any such person or corporation, in violation of the terms of this ordinance.

SEC. 4. It shall be the duty of the deputy smoke inspectors personally to inspect all chimneys, steam-generating plants, and all other furnace apparatus in use, excepting in private residences, mill-heating furnaces, and puddling furnaces, and to make written reports of the same to the chief smoke inspector, who shall keep a permanent record of all essential facts relating thereto. The chief smoke inspector or his deputies shall have authority to inspect and supervise all boilers or furnaces which are subject to the provisions of this ordinance, within the corporate limits of the city of Pittsburgh and upon the waters adjacent thereto, where such are within the jurisdiction of the provisions of this ordinance, and shall further have authority to examine and supervise the igniting, stoking, feeding, and attending such boiler or other furnace fires, and for that purpose, he or his duly appointed assistants shall also have authority to enter any steam boiler or engine room, or any building from which dense black or dense gray smoke is being emitted, and during the preceding twenty-four hours has been emitted; and any person or persons hindering or obstructing them in the performance of such duty shall be guilty of a violation of this ordinance.

SEC. 5. If the escape of smoke is the dense black or dense gray smoke which is prohibited within the meaning of this ordinance, the chief smoke inspector shall make complaint to the persons so offending, defining the offense. In the event that the cause thereof is unskillful stoking, he shall cause one of his assistants to give proper instructions to correct same and he shall make immediate complaint to the director of the department of public health against any and all such persons violating this ordinance. In the event that said offense is owing to the faulty construction of the furnace, size or height of stack connections, or other engineering details relating to boiler or other furnace construction or connection, he shall make statement of the cause of such offense and report to the owners or operators as to the necessary changes, alterations, or additions to be made; and in such case such time for such alterations or repairs in no instance shall exceed six (6) months. In the event that it should appear from the inspection of the chief smoke inspector that no change or alteration of the furnace, furnace connections, stack, or appurtenances thereto would eradicate said offense, and that said offense is owing to a plant being worked to excess of its normal capacity, or for other organic reason can not be converted by such changes into a plant which is not an offender within the meaning of this ordinance, then he shall report to the owners or operators as above mentioned the conditions of such plant and the required changes or additions necessary therein, so that it may not be operated as an offender. Not more than nine (9) months shall be allowed in which to complete such changes. Notices as above shall be in writing, and at the expiration of the time allowance the chief smoke inspector shall investigate and make report to the director of the department of public health as to the condition of the plant, who, in the event it is maintained as an offender against the provisions of this ordinance, may cause suit to be entered, as provided by law, against any and all persons in charge who are violating this ordinance.

SEC. 6. All accidents to furnaces or smoke-preventing devices in use, excepting in private residences, mill-heating furnaces, and puddling furnaces, shall be reported within seventy-two (72) hours to the chief smoke inspector, giving the nature of the accident and the time required to repair the same. Failure to make such report shall constitute a violation of this ordinance.

SEC. 7. During the first hour in which a new fire is being kindled in or under a cold boiler or other furnace, excepting in private residences, mill-heating furnaces, and puddling furnaces, sixty (60) minutes once a day for the first year, forty-five (45) minutes once a day for the second year, and thirty (30) minutes once a day for the third year, and each and every year thereafter of dense black or dense gray smoke issuing from the stack or chimney thereof will not be a violation of this ordinance; but during each succeeding hour that such boiler or other furnace is in service more than eight (8) minutes of dense black or dense gray smoke issuing from the chimney or stack thereof in any one hour shall be, and the same is, a violation of this ordinance.

SEC. 8. As an official chart to be used by smoke inspectors for determining the density of smoke in the city of Pittsburgh, Ringelmann's smoke scale, as supplied by the United States Geological Survey, shall be used. The third shade in density on said scale shall be known as dense gray, and the fourth shade in density shall be known as dense black.

SEC. 9. The owner or owners, the officers, managers, or agents of any corporation owning, leasing, or occupying, and any person operating or having charge or controlling any furnace, boiler, heating, or power or manufacturing plant, any locomotive, portable engine or boiler, street roller, motor vehicle self-propelled on a public street, steamboat, stationary engine or boiler, or any building or structure of any description emitting dense black or dense gray smoke, or by or from which dense black or dense gray smoke is emitted, except in the cases exempt under the terms of this ordinance and except for the times hereinbefore specified in sections 1, 2, and 7, shall be deemed guilty of violating the provisions of this ordinance, and upon conviction thereof before any alderman or police magistrate he or they or any other person being convicted of violating any of the provisions of this ordinance before any alderman or police magistrate shall be fined not less than ten ($10) dollars nor more than one hundred ($100) dollars, and in default of the payment of said fine and costs shall be committed to the Allegheny County Workhouse for a period not exceeding thirty (30) days for each offense, and each day in which such smoke shall be so emitted shall constitute a separate and distinct offense.

SEC. 10. That any ordinance or part of ordinance conflicting with the provisions of this ordinance be, and the same is hereby, repealed so far as the same affects this ordinance.

The Des Moines ordinance is presented as an example of an ordinance drawn for a relatively small city in which high-volatile coals are burned almost exclusively. It reads as follows:

Be it ordained by the city council of the city of Des Moines:

SECTION 1. The emission of dense smoke from the smokestack of any locomotive or engine, or from the smokestack of any stationary engine, or from the smokestack, chimney, or fireplace of any building or plant anywhere within the city of Des Moines shall be deemed, and is hereby declared, to be a public nuisance and is hereby prohibited except as hereinafter provided.

SEC. 2. The owner or owners of any locomotive engine and the general manager, superintendent, yardmaster, or other officer of any railroad company having charge or control of the operation of any locomotive engine who shall cause, permit, or allow dense smoke to issue or be emitted from the smokestack of any such locomotive engine within the city of Des Moines, except as hereinafter provided, shall be deemed and held guilty of creating a public nuisance and of violating the provisions of this ordinance.

SEC. 3. The owner, lessee, or occupant of any building or plant and the fireman, engineer, or any other person having charge or control of any furnace, fireplace, or stationary engine who shall cause, permit, or allow dense smoke to issue or be emitted from the smokestack, fireplace, or chimney of any such building or plant, or from the smokestack, fireplace, or chimney connected with any such plant, furnace, or stationary engine within the city of Des Moines, except as hereinafter provided, shall be deemed and held guilty of creating a public nuisance and of violating the provisions of this ordinance.

SEC. 4. There is hereby established as a part of the department of public safety a department of smoke inspection, the head of which shall be known as the smoke inspector.

SEC. 5. The smoke inspector shall be appointed by the city council, and the person so appointed shall be qualified by training and experience in the theory and practice of the construction and operation of steam boilers and furnaces in their relation to smoke abatement and the prevention of the emission of dense smoke therefrom. He shall, before entering upon his duties, execute a bond with the city of Des Moines in the sum of $1,000, the sureties to be approved by the city council, conditioned upon the faithful performance of the duties of the office. His salary shall be fixed by the city council.

SEC. 6. The city council shall appoint a smoke-abatement commission, composed of five members, who shall act as advisors to the smoke inspector in the conduct of the department. The smoke inspector shall at all times receive, place, and keep on file in his office all suggestions, recommendations, advice, and other communications which may be presented to him in writing by the smoke-abatement commission.

SEC. 7. No new plants or any reconstruction of old plants for producing power and heat, or either of them, either for sale or manufacturing purposes, or any new chimney, furnace, or fireplace connected with such plant or any steam plant shall be erected or maintained in the city until plans and specifications of the same have been filed in the office of and approved by the smoke inspector. and a permit issued by him for such erection, reconstruction, or maintenance: *Provided*, That in case of controversy as to the sufficiency of such plans and specifications and the provisions made therein for fuel combustion said plans and specifications shall be submitted to the smoke-abatement commission, one of whom shall have had experience in the installation and conduct of power and heating plants. The decision of said board shall be binding upon all parties. Such plans and specifications shall show the amount of work and the amount of heating to be done by such plant and all appurtenances thereto, including all provisions made for the purpose of securing complete combustion of the fuel to be used and for the purpose of preventing smoke and shall also contain a statement of the kind of fuel proposed to be used. Upon the approval of such plans and specifications, a duplicate set of which shall be left on file, and upon the payment of the fees as hereinafter provided the smoke inspector shall issue a permit for the reconstruction, erection, or maintenance of such plant. As soon as the smoke inspector has examined the plans and specifications submitted and has issued a permit as above provided, it shall be the duty of the inspector to see that the execution of the work permitted is carried out in conformity with the plans and specifications with special reference to the amount of space used, and size and construction of chimneys used, and the provisions for the prevention of smoke.

SEC. 8. It shall be unlawful for any person to use any new or reconstructed plant for the production and generation of heat and power, or either of them, either for sale or manufacturing purposes, until he shall have first procured a certificate from the smoke inspector that the plant is so constructed that it will do the work required, and that it can be so managed that no dense smoke shall be emitted from the chimney connected with the furnace or firebox, except as permitted in this ordinance.

SEC. 9. No owner shall alter or repair any chimney, fireplace, or any old furnace or device, which alteration, change, or installation shall affect the method or efficiency of preventing smoke, without first submitting plans and specifications to the smoke inspector and securing a permit therefor. In case of controversy the plans and specifications herein required shall be submitted to the smoke-abatement commission as provided in section 7 hereof: *Provided, however,* That minor necessary or emergency repairs which do not increase the capacity of such plant or which do not involve any substantial alteration in structure and which do not involve any alteration in the method or efficiency of smoke prevention may be made by or under the engineer in charge of said plant without a permit. A violation of this section shall subject the guilty party to a fine of not to exceed $25 for each day upon which he shall prosecute such alterations, change, or installation without a permit, and each day's violation shall constitute a separate offense.

SEC. 10. The fees for the inspection of plans and issuing of permits and for the inspection of plants and issuing of certificates shall be as follows:

For inspecting plans and new plants and plants about to be reconstructed, $1.50.

For inspecting plans for repairs and alterations, $1.50.

For examining a plant after its erection or reconstruction and before its operation and maintenance, $1.50.

The fee paid for the inspection or examination shall include the issuing of a permit or certificate in case such permit or certificate is granted. No fees shall be charged for detached residences.

SEC. 11. The issuance and delivery by the smoke inspector of a permit or certificate for the construction or reconstruction or for the alteration or repair of any plant, fireplace, or chimney connected with the plant shall not be held to exempt any person or corporation to whom any such permit has been issued or delivered or who is in possession of any such permit from prosecution on account of the emission or issuance of dense smoke contrary to the provisions of this ordinance.

SEC. 12. The city shall provide such instruments, books, papers, and equipment as shall be necessary for the proper performance of the duties of the smoke inspector, and he shall have charge of such instruments, books, papers, and equipment, and shall deliver the same to his successor in office.

SEC. 13. The smoke inspector shall cause to be kept in his office a complete record of all plans submitted, and of all permits issued, and of all examinations of plants made, and also all certificates issued. He shall make a report of the work of his department to the city council annually, on or before the 1st day of April, and at other times as often as required by the city council.

SEC. 14. If any smoke inspector acting on behalf of the city under the provisions of this chapter shall take or receive any money or any valuable thing or favor for the purpose of favoring any person or persons, or if any inspector shall recommend the issue of any certificate of inspection without having at the time stated thoroughly examined and tested the furnace, device, or apparatus so certified, he shall be subject to a fine of $100 for each offense, and it shall be the duty of the council to promptly suspend from office any smoke inspector against whom a charge of this kind is made, and upon conviction to promptly remove said inspector from office.

SEC. 15. For the purposes of this ordinance " chart," when used, means Ringelmann's smoke chart, as published and used by the United States Geological Survey.

" Stack " means any chimney, smokestack, or other structure, whether of brick, metal, or other material, intended for the emission of smoke. Smokejacks on locomotive roundhouses shall be deemed stacks and a part of the locomotive beneath them for the time being.

SEC. 16. The emission of dense smoke of a degree of density of No. 3 of the chart or greater for more than 6 minutes in any one hour from any stack, chimney, smokestack, or other structure for the purpose of emitting smoke, except as hereinafter provided, is hereby prohibited: *Provided, however*, That until January 1, 1913, smoke of a degree of darkness or density equal to No. 3 of the chart or greater may be emitted for not more than 8 minutes in any one hour: *Provided further*, That in the case of locomotive engines the emission of dense smoke of a degree of density of No. 3 of the chart or greater for more than 40 seconds in any one period of 5 minutes is prohibited after the 1st of January, 1913, and until the 1st of January, 1913, smoke of the degree of density No. 3 of the chart or greater is prohibited for more than 1 minute in any period of 5 minutes: *Provided, further*, That the stacks of locomotives moving trains of six cars or more may be permitted to emit smoke in any 5-minute period for 20 seconds in excess of that already provided for in this act, and that stacks of locomotives in and about roundhouses may emit smoke of a degree of density of No. 3 of the chart or greater for 60 minutes during the period when the fire is being built or rebuilt after cleaning the boiler. The number of minutes or seconds during which the smoke may be emitted in any period as provided in this section shall be deemed to mean the aggregate number of minutes or seconds, and such minutes or seconds need not be consecutive.

SEC. 17. The council may by resolution divide the city into districts and may except from the provisions of this ordinance chimneys emitting smoke from brick and tile kilns or other plants within districts outside of the central part of the city.

SEC. 18. It shall be the duty of the smoke inspector to enforce the provisions of this ordinance, to investigate all complaints made with reference to any violations thereof. Upon the filing with said inspector of a complaint it shall be his duty to proceed at once, either by himself or his assistants, to take observations of the stacks or chimneys complained of, testing the density of the smoke by the chart hereinbefore referred to, and it shall be his duty to keep a record of all such observations, which observations and records shall be open to public inspection at reasonable times and under reasonable regulations. It shall be the inspector's duty to prosecute all persons violating the provisions of this ordinance regulating the emission of dense smoke, and in all cases where the punishment by fine fails to abate the nuisance he shall cause to be brought in the district court in and for Polk County an action for the abatement thereof. All such prosecutions shall be in the name of the city of Des Moines.

SEC. 19. Temporary permits for the emission of smoke covering periods not exceeding six months from July 1, 1911, may be granted by the council to any person duly applying for the same and satisfying the council that he will make changes or improvements to prevent the emission of smoke in violation of the provisions hereof, but after July 1, 1912, no further permits shall be granted unless the council is satisfied that public convenience requires it, and permits so granted shall be for a period not exceeding six months.

SEC. 20. On and after the passage of this ordinance and until the 10th day of April, 1912, all of the duties herein enjoined upon the smoke inspector shall be performed by the person filling the office of fire marshal.

SEC. 21. Any person or corporation who shall violate any of the provisions of this ordinance, except as herein otherwise provided, shall be fined not less than $10 nor more than $100 for each offense.

SEC. 22. This ordinance being deemed urgent and necessary for the public peace, health, and safety, shall be in full force and effect from and after its passage and publication as provided by law.

Signed September 6, 1911.

JAS. R. HANNA, *Mayor.*

The present ordinance of the city of Milwaukee is presented below:

The common council of the city of Milwaukee do ordain as follows:

SECTION 1. Chapter 21 of the general ordinances of the city of Milwaukee, passed May 28, 1906, is hereby amended to read as follows:

" SECTION 1. There is hereby created a new office for the city of Milwaukee which shall be known as the office of smoke inspector, and the person occupying that office at any and all times shall be known by the title of smoke inspector. Such inspector shall be appointed by the mayor, subject to confirmation by the common council, and shall hold office for the term of four years, provided that the mayor may suspend said inspector for cause, and when so suspended shall cease to exercise the functions of his office until he shall be reinstated. Pending the period of suspension, the duties of the office shall be performed by the deputy smoke inspector oldest in the service. In case of such suspension, the mayor shall at once communicate to the common council the charges against the inspector, and the president of the council shall thereupon appoint a committee of five members of the council to consider and examine the same, giving the inspector an opportuntiy to be heard. Said committee shall report to the council as soon as may be its findings and recommendations. If the charges shall not be sustained by the council the inspector shall be immediately reinstated. If the council shall determine that the charges are sustained they shall at once determine whether the good of the city requires that the suspended inspector shall be removed from office or shall be suspended from office without pay for a fixed period. The council shall communicate their decision to the mayor in writing, who shall thereupon make it public. The present incumbent of the existing office of smoke inspector shall be considered appointed as smoke inspector under this ordinance.

"No person shall be eligible to said office unless he is by trade or profession a steam or mechanical engineer with an active practical experience of at least five years in working at said trade or profession. Before entering upon the duties of his office the inspector shall take the oath of office prescribed by the charter. It shall be the duty of the smoke inspector to see that the provisions of this ordinance and all ordinances supplemental to or amendatory thereof and the laws of the State of Wisconsin relating to the suppression of smoke shall be enforced. He shall keep a full and complete record of all the transactions of his office, which shall at all reasonable times be open to public inspection. He shall be provided with an office in the city hall.

"SEC. 2. The salary of the smoke inspector shall be $2,000 per annum, payable in equal monthly installments at the same time and in the same manner that the salaries of other city officials are paid.

"SEC. 3. The said inspector is authorized to employ one clerk, to be selected from the civil-service list of the city, and the clerk shall attend to such duties as the inspector shall direct. The salary of said clerk shall be seventy-five dollars ($75) per month, to be paid monthly from the city treasury in the same manner that the salaries of other city employees are paid.

"SEC. 4. The smoke inspector is authorized to employ two deputy smoke inspectors, to be selected from the civil-service list of the city, and the deputy smoke inspectors shall attend to such duties as the inspector shall direct. The salary of each deputy inspector shall be one hundred dollars ($100) per month, to be paid monthly from the city treasury in the same manner that the salaries of other city employees are paid. The deputy inspectors may be discharged by the inspector for cause.

"SEC. 5. The smoke inspector shall forward to the comptroller on or before the 1st day of November of each year an estimate of the needs of his office.

"SEC. 6. To emit or cause or permit to be emitted into the open air within the corporate limits of the city of Milwaukee, or within 1 mile therefrom, any dense smoke shall be, and is hereby declared to be, a nuisance, and the same is hereby prohibited: *Provided*, That nothing herein contained shall prohibit the emission of dense smoke not to exceed five minutes in any one hour of the day or night.

"The owner or owners of any boat, stationary or locomotive engine, engine used in dredging or driving piles, portable boiler or furnace or tar kettle, and any officer, manager, or agent of any corporation owning any boat, stationary or locomotive engine, engine used in dredging or driving piles, portable boiler or furnace or tar kettle, and the owner, lessee, or occupant of any building, and any officer, manager, or agent of any corporation or company owning, leasing, or occupying any building from which dense smoke is permitted or allowed to issue or to be emitted within the corporate limits of the city of Milwaukee, or within 1 mile therefrom, shall for every such first offense be punished by a fine of not less than twenty-five dollars ($25) nor more than one hundred dollars ($100), and in default of payment by imprisonment in the house of correction of Milwaukee County for a term not to exceed sixty (60) days; for a second offense by a fine of not less than fifty dollars ($50) nor more than one hundred dollars ($100), and in default of payment by imprisonment for a term not to exceed sixty (60) days; for a third and every subsequent offense by a fine of not less than one hundred dollars ($100) nor more than two hundred dollars ($200), and in default of payment by imprisonment for a term not to exceed six (6) months.

"SEC. 7. The smoke inspector shall have the right to enter in the performance of his duties at all reasonable hours all premises where any dense smoke is emitted or where any such boiler or engine is located.

"SEC. 8. Before any person or persons, firm or member of any firm or corporation, or any officer of any corporation, shall construct or alter any stationary steam plant, boiler, or furnace within the corporate limits of the city of Milwaukee, he or they shall make application at the office of the smoke inspector for a permit for that purpose, and shall furnish a written statement, giving the style and dimensions of such steam plant, boiler, or furnace, together with the height and size of stack or chimney and the method or device to be adopted for the prevention of the emission of dense smoke therefrom; and if the matters mentioned in said application and statement be approved by said inspector, he shall issue a permit for the construction of such steam plant, boiler, or furnace. Any person or persons, firm or member of any firm or corporation, or any officer of any corporation who proceeds in such construction or alteration without said permit shall be deemed guilty of a violation of this ordinance, and shall be subject to such penalties as are provided in section 6 of this chapter.

"SEC. 9. All accidents to stationary steam boilers, furnaces, or smoke-preventing devices shall be reported to the smoke inspector in writing, giving the nature of the accident and the time required to repair the same."

SEC. 10. All ordinances or parts thereof contravening or conflicting with the provisions of this ordinance are hereby repealed.

SEC. 11. This ordinance shall take effect and be in force from and after its passage and publication.

Approved, October 12, 1911.

EMIL SEIDEL, *Mayor.*

The Los Angeles ordinance is presented because it was adopted by a city in which oil is the principal fuel.

The mayor and council of the city of Los Angeles do ordain as follows:

SECTION 1. That for the purpose of regulating the discharge of smoke from flues, chimneys, or smokestacks, or from any other structures or appliances from which smoke is discharged, and for the purpose of determining by a comparison the degree of darkness of smoke so discharged, a color scale for the measurement thereof is hereby adopted, as follows:

A white card not less than 5 by 8 inches in size shall be marked with black lines crossing each other at right angles. Each such line shall be 1 millimeter in width and such lines shall be so placed that white spaces 9 millimeters square shall remain between such lines. When a test is being made such card shall be placed at a distance of not more than 55 feet and not less than 45 feet from the observer and as nearly in line as possible between the eyes of the observer and the smoke concerning which the test is being made.

SEC. 2. It shall be unlawful for any person, firm, or corporation to cause, permit, or allow any smoke of a greater degree of darkness than the card described in section 1 hereof when such card is placed at the said distance from the person observing such smoke, to issue or to be discharged from any flue, chimney, or smokestack, or from any other structure or appliance used for the discharge of smoke, or from which smoke is discharged, or from any works, plant, or factory, for a period longer than or for periods aggregating more than five minutes in any one hour of the day or night.

For the purposes of this section a works, plant, or factory shall be deemed to include all buildings and appliances, and all flues, chimneys, and smokestacks connected therewith, and all structures and appliances from which smoke is discharged, located upon any parcel of land which is held, used, or occupied in one body, whether the same contains one or more lots or tracts of land, if such buildings, structures, and appliances, and such flues, chimneys, and smokestacks are owned or used, or are intended to be used by the same person, firm, or corporation in or about the conduct of any business or occupation.

Sec. 3. It shall be unlawful for any person, firm, or corporation to cause, permit, or allow soot, ashes, or cinders to issue or to be discharged from any flue, chimney, or smokestack, or from any other structure or appliance.

Sec. 4. If any flue, chimney, smokestack, or other structure or appliance shall become so filled with soot as to become a menace to adjacent property, it shall be the duty of the person, firm, or corporation owning or using such flue, chimney, smokestack, or other structure or appliance to cause the same to be thoroughly cleaned, and it shall be unlawful for any such person, firm, or corporation to fail, refuse, or neglect so to do. Each such person, firm, or corporation shall be deemed guilty of a separate offense for every day during which such failure, refusal, or neglect continues and shall be punishable therefor as provided by this ordinance.

Sec. 5. It shall be unlawful for any person, firm, or corporation to erect, construct, or maintain, or to cause or permit to be erected, constructed, or maintained any flue, chimney, or smokestack within 50 feet of any window of any adjacent building unless the top of such flue, chimney, or smokestack shall be higher than every portion of such window: *Provided, however*, That the provisions of this section shall not apply in any case where the owner of such adjacent building shall refuse to grant permission to brace such flue, chimney, or smokestack by means of wires attached to such building.

Sec. 6. All officers and inspectors of the health department of the city of Los Angeles are hereby authorized to enter, during reasonable hours, upon any premises upon which is located any flue, chimney, or smokestack, or any other structure or appliance from which any smoke, soot, ashes, or cinders shall be discharged, for the purpose of making an examination as to the cause of the discharge of such smoke, soot, ashes, or cinders, and for the purpose of ascertaining the kind or character of fuel used, and the manner of using the same, and any other fact or facts showing compliance with or violation of this ordinance. Such officers and inspectors shall at least twice each month make a detailed report to the board of health of each such examination, which report shall show all facts ascertained by such examination.

Sec. 7. That any person, firm, or corporation violating any of the provisions of this ordinance shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be punishable by a fine of not more than two hundred dollars ($200) or by imprisonment in the city jail for a period of not more than one hundred (100) days, or by both such fine and imprisonment.

Sec. 8. That ordinance No. 15597 (new series), entitled "An ordinance regulating the discharge of smoke from flues, chimneys, smokestacks, or other structures or appliances from which smoke is discharged, in the city of Los Angeles," approved October 24, 1907, and ordinance No. 16043 (new series), entitled "An ordinance regulating the discharge of soot, ashes, and cinders from flues, chimneys, smokestacks, or other structures or appliances in the city of Los Angeles," approved February 5, 1908, and all ordinances amendatory thereto or thereof, and all other ordinances in conflict with this ordinance be, and the same are hereby, repealed.

Approved February 23, 1911.

Geo. Alexander, *Mayor.*

The Massachusetts act providing for the abatement of smoke in the city of Boston and vicinity reads as follows:

Be it enacted, etc., as follows:

SECTION 1. In this act, unless the context otherwise requires—

"Board" means the board of gas and electric light commissioners—

"District" means the district to which the provisions of this act shall apply, to wit, that part of Boston harbor lying westerly of a line drawn from the southeastern point of Deer Island to the northeastern point of Long Island and the territory comprised within the cities of Boston, Cambridge, Somerville, Everett, and Chelsea, and the town of Brookline.

"Chart" means Ringelmann's smoke chart, as published and used by the United States Geological Survey.

"Stack" means any chimney, smokestack, or other structure, whether of brick, metal, or other material intended for the emission of smoke. Smokejacks on locomotive roundhouses shall be deemed stacks and a part of the locomotive beneath them for the time being.

For the purposes of this act stacks shall be classified as follows:

Class I includes all fixed or stationary stacks having an inside area at the top not exceeding the area of a circle 5 feet in diameter.

Class II includes all fixed or stationary stacks having an inside area at the top greater than the area of a circle 5 feet in diameter but not exceeding the area of a circle 10 feet in diameter.

Class III includes all fixed or stationary stacks having an inside area at the top greater than the area of a circle 10 feet in diameter.

Class IV includes all stacks of vessels having an inside area at the top not exceeding the area of a circle 4 feet in diameter.

Class V includes all stacks of vessels having an inside area at the top greater than the area of a circle 4 feet in diameter.

Class VI includes all stacks on steam locomotives.

SEC. 2. The emission of smoke of a degree of darkness or density equal to No. 2 of the chart, or greater, for more than 6 minutes in any one hour from stacks of Class I; or of a degree equal to No. 3 of the chart, or greater, for more than 3 minutes in any one hour from stacks of Class II; or of a degree equal to No. 2 of the chart, or greater, for more than [illegible] minutes in any one hour, but not exceeding during said 25 minutes a degree equal to No. 3 of the chart, or greater, for more than 5 minutes from stacks of Class III; or of a degree equal to No. 3 of the chart, or greater, for more than 3 minutes in any one hour from stacks of Class IV, for more than 5 minutes in any one hour from stacks of Class V, and for more than 20 seconds in any one period of 5 minutes from stacks of Class VI, is hereby prohibited.

Provided, however, That during the calendar year 1910 smoke of a degree of darkness or density equal to No. 3 of the chart, or greater, may be emitted for not more than 6 minutes in any one hour from stacks of Class I; and smoke of a degree equal to No. 4 of the chart, or greater, for not more than 5 minutes in any one hour from stacks of Class II, and for not more than 10 minutes in any one hour from stacks of Class III, and for not more than 9 minutes in any one hour from stacks of Class IV, and for not more than 12 minutes in any one hour from stacks of Class V; and of a degree equal to No. 3 of the chart, or greater, for not more than 40 seconds in any one period of 5 minutes from stacks of Class VI; and during the calendar year 1911 smoke of a degree of darkness or density equal to No. 3 of the chart, or greater, may be emitted for not more than 4 minutes in any one hour from stacks of Class I, and for not more than 10 minutes in any one hour from stacks of

Class II; and of a degree equal to No. 3 of the chart, or greater, for not more than 20 minutes in any one hour, but not exceeding during said 20 minutes a degree equal to No. 4 of the chart, or greater, for more than 5 minutes from stacks of Class III; and of a degree equal to No. 3 of the chart, or greater, for not more than 12 minutes in any one hour from stacks of Class IV, and for not more than 15 minutes in any one hour from stacks of Class V, and for not more than 30 seconds in any one period of 5 minutes from stacks of Class VI; and during the calendar year 1912 smoke of a degree of darkness or density equal to No. 2 of the chart, or greater, may be emitted for not more than 8 minutes in any one hour from stacks of Class I; and of a degree equal to No. 3 of the chart, or greater, for not more than 6 minutes in any one hour from stacks of Class II; and of a degree equal to No. 2 of the chart, or greater, for not more than 30 minutes in any one hour, but not exceeding during said 30 minutes a degree equal to No. 3 of the chart, or greater, for more than 10 minutes from stacks of Class III; and of a degree equal to No. 3 of the chart, or greater, for not more than 7 minutes in any one hour from stacks of Class IV, and for not more than 9 minutes in any one hour from stacks of Class V.

And provided further, That stacks of locomotives, moving trains of 6 cars or more, be permitted to emit smoke in any 5-minute period for 10 seconds in excess of that already provided for in this act, and that stacks of Class VI, in and about roundhouses, may emit smoke for 30 minutes during the period when the fire is being built, or rebuilt after cleaning. The number of minutes or seconds during which smoke may be emitted in any period as provided in this section shall be deemed to mean the aggregate number of minutes or seconds, and such minutes or seconds need not be consecutive.

Table showing the density of smoke, in accordance with the Ringelmann chart, which may be emitted from the various classes of stacks as provided in section 2, and the duration of such emission.

Year.	Class of stack.													
	1		2		3		4		5		6		Locomotives moving trains of 6 cars more.	
	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Minutes per hour.	Chart number.	Seconds in 5-minute periods.	Chart number.	Seconds in 5-minute periods.
1910	3	6	4	5	4	10	4	9	4	12	3	40	3	50
1911	3	4	3	10	3 including 4	20 including 5	3	12	3	15	3	30	3	40
1912	2	8	3	6	2 including 3	30 including 10	3	7	3	9	3	20	3	30
1913	2	6	3	3	2 including 3	25 including 5	3	3	3	5	3	20	3	30

SEC. 3. The board shall appoint a smoke inspector who shall not engage in any other business, and such deputy inspectors as it may think proper, who shall be sworn to the faithful performance of their duties and shall hold office during the pleasure of the board. The board may also employ such clerks, stenographers, and other office employees as it may deem necessary, and may expend for necessary office rent, books, stationery, travel, and other expenses incidental to the performance of the duties imposed by this act, such sum as the legislature shall annually appropriate. The compensation of inspectors, deputy inspectors, and all other employees shall be fixed by the board, subject to the approval of the governor and council. All salaries and other expenses provided for by this act shall be paid by the Commonwealth, which shall be reimbursed as hereinafter provided.

SEC. 4. It shall be the duty of the board to enforce the provisions of this act, to investigate all complaints made with reference to any violations thereof, and in its discretion to order any person or corporation complained of to comply with the provisions of this act, and to enforce such orders by legal proceedings. The board shall make an annual report to the general court of its doings with such recommendations as to the legislative action or State policy as it may deem advisable. The board, with the approval of the governor and council, may make such rules and regulations as it deems advisable for its own government, for the government of its employees and assistants, for the observation of smoke by the inspector or his duly authorized agents at reasonable intervals, and for keeping proper records of all observations. Such observations and records shall be open to public inspection at reasonable times and under reasonable regulations.

SEC. 5. It shall be the duty of the smoke inspector, by himself and his assistants, to assist the board in the performance of its duties, in such manner as the board shall direct, to investigate complaints as to violations of this act, to collect evidence in regard to the same and present such evidence to the board for action.

SEC. 6. The board shall have power, after notice and a hearing, to order any person or corporation having control of the operation of the stack, other than an employee, to stop or abate the emission of smoke in violation of this act. Such notice shall be in writing and may be served personally upon such person or corporation, or duly authorized agent by any person authorized by the board to make such service, and in the manner provided by the laws of the Commonwealth for the service of writs returnable to the superior court. Such notice shall be served at least 48 hours before the time fixed for the hearing, and a copy of the order or decree of the board shall in like manner be served upon such person or corporation or duly authorized agent within 24 hours after the same shall be made by the board. In the event of violation, a copy of the observation made in accordance with section 4 shall be mailed within 24 hours to the person or corporation having control of the operation of the stack, and an additional copy shall be delivered upon the premises, as soon as is practicable to the employee having charge of the stack, unless it is otherwise requested in writing by any such person or corporation.

SEC. 7. Any person or corporation violating any order of the board shall be guilty of a misdemeanor and may be punished by a fine of not less than ten nor more than fifty dollars for the first offense and not less than twenty nor more than one hundred dollars for every succeeding offense. No person or corporation shall be deemed guilty in accordance herewith, unless the observations, used as evidence at the trial, shall be made as provided in section 4. The superior court sitting in equity, on petition of the board or any person authorized by the board, shall have jurisdiction to restrain violations of this act during the prosecution of any proceeding at law for the enforcement of any order of the board.

SEC. 8. Temporary permits for the emission of smoke, covering periods not exceeding six months from June 1, 1910, may be granted by the board to any person duly applying for the same and satisfying the board that he will make changes or improvements to prevent the emission of smoke in violation of the provisions hereof. But after December 1, 1910, no further permits shall be granted unless the board is satisfied that public convenience requires it, and permits so granted shall be for a period not exceeding six months.

SEC. 9. The board shall annually estimate the expense of carrying this act into effect for the ensuing year and shall certify the same to the treasurer of the Commonwealth, who shall apportion said expense among the cities and towns comprised in the district in proportion to the amount of their State tax, and the treasurer shall annually notify each city and town of the amount to be paid by it, and the same shall be paid by such city or town into the treasury of the Commonwealth at the time required for the payment of, and as a part of, its State tax.

SEC. 10. All acts and parts of acts inconsistent herewith are hereby repealed, and this act shall take effect on the 1st day of July, 1910.

Approved June 15, 1910.

PUBLICATIONS ON FUEL TESTING.

The following Bureau of Mines publications may be obtained free by applying to the Director Bureau of Mines, Washington, D. C.:

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp., 1 pl.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 9. Recent development of the producer-gas power plant in the United States, by R. H. Fernald. 82 pp., 2 pls. Reprint of United States Geological Survey Bulletin 416.

BULLETIN 11. The purchase of coal by the Government under specifications, by G. S. Pope. 80 pp. Reprint of United States Geological Survey Bulletin 428.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl.

BULLETIN 18. The transmission of heat into steam boilers, by Henry Kreisinger and W. T. Ray. 1912. 380 pp.

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 64 pp. Reprint of United States Geological Survey Bulletin 367.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls. Reprint of United States Geological Survey Bulletin 366.

BULLETIN 28. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 51 pp. Reprint of United States Geological Survey Bulletin 323.

BULLETIN 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. Reprint of United States Geological Survey Bulletin 382.

BULLETIN 30. Briquetting tests at the United States fuel-testing plant at Norfolk, Va., 1907–8, by C. L. Wright. 41 pp., 9 pls. Reprint of United States Geological Survey Bulletin 385.

BULLETIN 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 29 pp. Reprint of United States Geological Survey Bulletin 393.

BULLETIN 32. Commercial deductions from comparisons of gasoline and alcohol tests on internal-combustion engines, by R. M. Strong. 38 pp. Reprint of United States Geological Survey Bulletin 392.

BULLETIN 33. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 50 pp. Reprint of United States Geological Survey Bulletin 403.

BULLETIN 34. Tests of run-of-mine and briquetted coal in a locomotive boiler, by W. T. Ray and Henry Kreisinger. 33 pp. Reprint of United States Geological Survey Bulletin 412.

BULLETIN 35. The utilization of fuel in locomotive practice, by W. F. M. Goss. 29 pp. Reprint of United States Geological Survey Bulletin 402.

BULLETIN 36. Alaskan coal problems, by W. L. Fisher. 1911. 32 pp., 1 pl.

BULLETIN 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel, by W. F. M. Goss. 58 pp., 4 pls. Reprint of United States Geological Survey Bulletin 363.

BULLETIN 39. The smoke problem at boiler plants, a preliminary report, by D. T. Randall. 188 pp. Reprint of United States Geological Survey Bulletin 334, revised by S. B. Flagg.

BULLETIN 40. The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants, by D. T. Randall and H. W. Weeks. 188 pp.

Reprint of United States Geological Survey Bulletin 373, revised by Henry Kreisinger.

BULLETIN 41. Government coal purchases under specifications, with analyses for the fiscal year 1909–10, by G. S. Pope, with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls.

BULLETIN 43. Comparative fuel values of gasoline and denatured alcohol in internal-combustion engines, by R. M. Strong and Lauson Stone. 1912. 243 pp., 3 pls.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp.

TECHNICAL PAPER 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 5. The constituents of coal soluble in phenol, by J. C. W. Frazer and E. J. Hoffman. 1912. 20 pp.

TECHNICAL PAPER 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1912. 21 pp.

TECHNICAL PAPER 9. The status of the gas producer and of the internal-combustion engine in the utilization of fuels, by R. H. Fernald. 1912. 42 pp.

TECHNICAL PAPER 10. Liquefied products from natural gas; their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 16. Deterioration and spontaneous combustion of coal in storage, preliminary report, by H. C. Porter and F. K. Ovitz. 1912. 14 pp.

TECHNICAL PAPER 20. The slagging type of gas producer with a brief report of preliminary tests, by C. D. Smith. 1912. 14 pp.

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Bulletin 51

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, Director

THE ANALYSIS OF BLACK POWDER AND DYNAMITE

BY

WALTER O. SNELLING and C. G. STORM

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THE ANALYSIS OF BLACK POWDER AND DYNAMITE.

By Walter O. Snelling and C. G. Storm.

INTRODUCTION.

Although descriptions of the methods of analysis of explosives are to be found in many books on explosives, and in works on engineering chemistry or chemical analysis, most of these descriptions are incomplete and lacking in details. The methods of analysis employed in the laboratories of most explosives factories are frequently treated as trade secrets, and very little information is published from such laboratories.

This bulletin outlines the methods of analysis that are used by the Bureau of Mines in the examination of certain classes of explosives. The present form of most of these methods has been worked out in the bureau's explosives laboratory. The methods employed by Prof. C. E. Munroe were taken as a basis, and were elaborated to meet the demands incident to the treatment of complicated mixtures and to the development of the explosives art. A subsequent bulletin will discuss the methods of analysis of "permissible" explosives, many of the latter being of decidedly complicated character and requiring special treatment. This bulletin presents the methods of analysis of "ordinary" dynamite, and the ammonia, gelatin, low-freezing, and granular dynamites, and the common grades of black gunpowder and black blasting powder. The bulletin is published by the bureau for the information of all persons interested in explosives and their safe and efficient use in mining work.

As the term "ordinary" dynamite, though much used, has no conventional meaning, and may be used to cover a wide variety of compositions of matter, it may be noted that the standard dynamite used at the Pittsburgh testing station is a good example of the "ordinary" dynamite known in this country. This testing station dynamite has the following composition:

Composition of Pittsburgh testing station dynamite.

	Per cent.
Nitroglycerin	40
Sodium nitrate	44
Wood pulp	15
Calcium carbonate	1

As most permissible explosives contain only the constituents found generally in the various types of ordinary dynamite, the chemist will usually find it possible to analyze such explosives either wholly or partly by following the general methods of analysis here given for the type of explosive that seems most closely related to the one under examination. The methods of extraction with ether, with water, etc., here outlined are general methods which are applied with equal success to all classes of explosives, and therefore by the use of these general methods, following a thorough qualitative examination, little difficulty should be met except with those classes of permissible explosives that contain large amounts of salts holding water of crystallization, such as alum and magnesium sulphate, or those containing an unusual number of uncommon constituents. Even with such explosives, however, if the information desired is principally in regard to the percentages of explosive ingredients (nitroglycerin, ammonium nitrate, etc.), the methods outlined in this bulletin may be satisfactorily followed.

DYNAMITE.

"Ordinary" dynamite consists essentially of nitroglycerin absorbed in some porous material. Owing to its physical condition and its extreme sensitiveness to shock, liquid nitroglycerin is not suitable for use as an explosive in mining and quarrying, but when nitroglycerin is absorbed in a porous material a more or less plastic mass is obtained which is far less sensitive to shock than liquid nitroglycerin, although, when properly fired by means of a detonator, it retains most of the explosive properties of nitroglycerin. Among the many substances that have been used as absorbents for nitroglycerin are sawdust, wood pulp, ground mica, and infusorial earth (kieselguhr), or mixtures of these substances with alkaline nitrates and other substances.

It is usual to classify absorbents for nitroglycerin as active and inactive. Pulverized gunpowder, for example, or mixtures of wood pulp with sodium nitrate or other oxidizing agents, represent "active" absorbents, whereas mica, kieselguhr and similar materials, which play no part in the explosive reactions and which are employed merely to absorb or retain the liquid nitroglycerin, form the so-called "inactive" absorbents.

The type of dynamite most generally used to-day consists of nitroglycerin absorbed in a mixture of wood pulp and sodium nitrate, and to this mixture is usually added a small amount of some antacid such as calcium carbonate, magnesium carbonate, or zinc oxide. This antacid is added in the belief that it increases the stability of the resulting explosive by neutralizing such small amounts of free acid as may be produced by the decomposition of the nitroglycerin during long storage.

The analysis of dynamite is best carried out by first separating, with ether or some other appropriate solvent, the nitroglycerin from the dope in which it is absorbed. After the nitroglycerin has been thus removed, the soluble nitrate in the dope may be removed by dissolving in water; the antacid may then be dissolved in dilute acid, and the residue insoluble in ether, water, dilute acid, etc., may be directly determined by weight.

In its simplest form, therefore, the analysis of dynamite consists in the removal of the constituent materials, one by one, through the use of appropriate solvents. Dynamites of the most complicated composition may usually be analyzed in this way, through selective solution. In the present paper the methods of analyzing ordinary types of dynamite are discussed, and those that have been found best in an experience covering several thousand analyses are stated.

PHYSICAL EXAMINATION.

Upon receiving a sample of explosive for analysis it is desirable to record full information in regard to the size and weight of each cartridge, with a complete copy of any lettering that may appear on the wrapper. It is also advisable to record the nature of the outer wrapping paper (such as ordinary paper, parchmentized paper, or paper coated with paraffin), and whether the cartridge has been redipped; that is, placed in a paraffin bath after being filled. Whether a cartridge has been redipped can usually be determined by carefully opening the wrapper. If there is a greater thickness of paraffin near the edge where the sheet overlaps, or if the overlapping edge is attached to the adjacent portions of the paper by means of an adhering deposit of paraffin, it may be assumed that the cartridge has been redipped.

DETERMINATION OF GRAVIMETRIC DENSITY.

It is possible to determine approximately the gravimetric density or apparent specific gravity of a cartridge of explosive by measuring carefully the length and circumference of the cartridge, calculating from these figures the volume in cubic centimeters, and then dividing the weight in grams of the cartridge by this figure. However, experiments made at the bureau's explosives laboratory have shown that even with the most careful measurements the figures thus obtained are liable to be in error by as much as 10 to 20 per cent, a difference entirely too great to make the method permissible for exact work. With some redipped cartridges weighing in water has given satisfactory results, but cartridges seldom have a coating of paraffin so complete as to permit the use of this method. Accordingly a method was sought that would at all times give satisfactory results even with cartridges that had not been redipped.

The volume of the cartridge can be determined conveniently by using sand instead of water as the measuring material. A weighed glass cylinder about 30 cm. high and 5 cm. in inside diameter is filled with fine sand (preferably sea sand) that has been sifted through a 60-mesh sieve. A straight edge is drawn across the top of the cylinder, the level of the sand being left flush with the top edge, and the weight of the cylinder and contained sand is determined. From this weight the weight of the cylinder is subtracted and the result is the weight of the sand, which, divided by the weight of water required to fill the cylinder, gives the apparent specific gravity of the sand used. All the sand except enough to fill the cylinder to a depth of about 1 inch is now poured out, a weighed cartridge of the explosive is placed in the cylinder, and sand added until the cylinder is filled flush to the top as before, when it is struck with the straight edge and then the weight of cylinder and sand and cartridge is noted. From these figures the weight of sand displaced by the cartridge is found. This weight divided by the apparent specific gravity of the sand gives the volume of the cartridge. The weight of the cartridge divided by its volume gives its apparent specific gravity or gravimetric density. This determination leaves the cartridge in condition for use in sampling, if desired.

In making this determination care should be taken that the cylinder is filled each time in exactly the same manner, the sand being poured in slowly and not packed by jolting, shaking or otherwise. Repeated determinations of the weight of sand required to just fill the cylinder will prove that with proper care uniform results may be obtained; in practice this method has been found to be both rapid and exact.

TEST FOR LIABILITY OF EXUDATION.

To determine whether there is liability of leakage of nitroglycerin from cartridges containing this explosive, it is always advisable to make an exudation test, which indicates the amount of nitroglycerin that may be lost by the explosive tested under prescribed conditions. The tests most commonly used for this purpose are the 40° test, the pressure test, and the centrifugal test.

40° TEST FOR EXUDATION.

In the 40° test a cartridge of the explosive under examination is placed in a vertical position in an oven heated to 40° C. Some small perforations are made in the wrapper at the ends of the cartridge, and the cartridge is then placed on end on a small wire tripod in a small glass beaker or cylinder. The whole is then placed for six days in an oven maintained at a constant temperature of 40° C. At the end of this time an examination is made to see if any leakage of nitroglycerin in the form of drops has occurred. Such leakage may be taken as evidence that there is too much nitroglycerin in the explosive for the amount of absorbent material present, or that the dope used is deficient in absorbing capacity.

PRESSURE TEST FOR EXUDATION.

Before the centrifugal test was employed, it was customary to use a pressure test for exudation which consisted in exposing a sample of the dynamite to a definite pressure produced by a weight on a lever arm, and determining the amount of nitroglycerin thereby forced out of the dynamite. Many modifications of this test have been tried, in which cotton, blotting paper, or other absorbent material have been used to hold the nitroglycerin forced out from the explosive. The pressure test is unreliable and hence is not satisfactory in use. For example, by this test an explosive that contains a certain amount of a mixture of sawdust and wood pulp shows less exudation than one in which the same amount of absorbent is used in the form of wood pulp alone, a result that is clearly incorrect, since the absorbing power of wood pulp is much greater than that of sawdust. The reason for the more favorable result when the absorbent contains sawdust is that the particles of sawdust are packed together to form a cellular mass, which incloses the particles of wood pulp holding the nitroglycerin, thereby in a great measure protecting them from pressure.

CENTRIFUGAL TEST FOR EXUDATION.

The use of centrifugal force as a means of measuring the completeness with which nitroglycerin is absorbed in an explosive was some years ago suggested to Col. B. W. Dunn, chief inspector of the bureau for the safe transportation of explosives, by T. J. Wrampelmeier, an inspector in that bureau, and a device for testing the value of this method was made use of by C. P. Beistle,[a] chief chemist of that bureau. The method employed was to place the explosive, together with a perforated disk of vulcanite and an absorbent material such as cotton, within a glass tube, the tube being then placed in a centrifuge. The increase in weight of the cotton after rotation was taken as a measure of the amount of nitroglycerin lost by the explosive during the process. This apparatus gives much more satisfactory results than the former methods of testing by pressure alone, but owing to the fact that the cotton becomes compressed during rotation, thus changing the position of the vulcanite disk, the apparatus at times gives discordant results, and the figures from tests of any two explosives are not proportional to the relative tendency toward leakage of nitroglycerin under normal conditions.

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[a] Report of chief inspector of the bureau for the safe transportation of explosives, February, 1909.

One of the authors designed a centrifuge attachment which is now being used with reliable results by the Bureau of Mines. This apparatus is shown in Plate I, *A*. Two samples of the explosive are placed in ordinary porcelain Gooch crucibles, without mat, the crucibles being held above two other nonperforated crucibles in the manner shown. A small amount of cotton is placed in each of the lower crucibles to receive the exuded nitroglycerin, and the loss by exudation is determined by weighing the crucibles containing the explosive before and after rotation. The circle of rotation made by the bottom of the crucibles is 14 cm. in diameter, and the standard velocity of rotation is 600 revolutions (30 turns of the handle) per minute. The usual test consists in placing 8 grams of explosive in each of the upper crucibles, and determining the loss in weight after rotating at the velocity of 600 revolutions per minute for 5 minutes at a temperature of about 20° C. If the explosive does not lose more than 5 per cent in weight it is considered to have satisfactory absorbing capacity, but if more than 5 per cent is lost its absorbent properties are considered deficient, and in the transportation or use of such an explosive there is considered to be liability of accident.

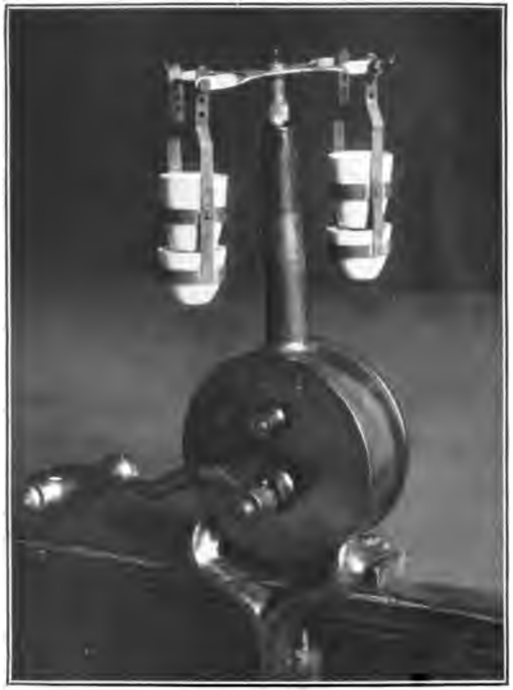
TEST FOR STABILITY.

Many tests have been proposed for determining the stability of explosives under the influence of heat, and much has been written in regard to the comparative accuracy of these different tests. This field is now being investigated by the bureau, and a special report thereon will be issued. At present all mining explosives examined by the bureau are tested for stability by means of the Abel heat test.

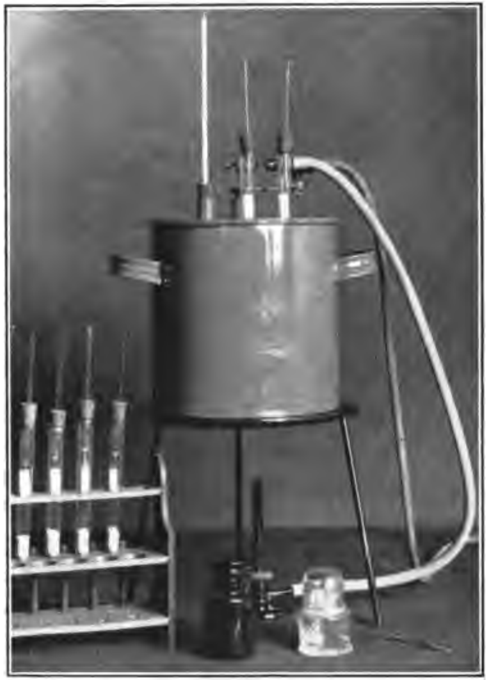
ABEL TEST.

The Abel stability test depends upon the fact that when potassium iodide is decomposed in the presence of starch, the iodine liberated reacts with the starch to form a colored body. The explosive to be tested is placed in a stoppered test tube and heated in a constant-temperature bath until the oxides of nitrogen liberated as decomposition products make a brownish color on a strip of potassium iodide starch paper suspended in the tube above the explosive. The stability of the explosive is judged by the time required for the production of a coloration of a standard intensity. The apparatus used in the Abel test is illustrated in Plate I, *A*.

Two grams of explosive in its original condition, without preliminary drying or preparation other than thorough mixing, is placed in



A. CENTRIFUGE FOR EXUDATION TEST OF DYNAMITE.



B. APPARATUS FOR ABEL HEAT TEST.

a glass tube. The tube is of standard dimensions as follows: Length, 14 cm. (5½ inches); inside diameter, not less than 1.27 cm. (½ inch); outside diameter, not more than 1.59 cm. (⅝ inch); thickness of the glass, about 1.2 mm. ($\frac{3}{64}$ inch). The tube is closed by a clean, tightly fitting cork stopper, through which passes a glass rod provided with a platinum hook, fused into the lower end for holding the test paper. The test papers, in pieces about 2.5 cm. (1 inch) by 1.0 cm. (⅜ inch), are hung on the platinum hooks (forceps being used in handling) and the upper half of each strip of test paper is moistened with a solution of equal volumes of pure glycerin and water.

The test paper used is potassium iodide starch paper, similar to that prepared by Eimer & Amend (Frankford Arsenal formula), or prepared by a standard method as described below. The heat-test bath is placed so that a good light—not direct sunlight—is transmitted through the test papers to the operator. The bath temperature is maintained constant within 0.5° C. of the desired temperature (71° C.), the thermometer being so immersed that the bottom of the bulb is 2½ inches below the top of the bath.

All determinations are made in duplicate. The shorter time required to bring one of the two test papers to the prescribed tint determines the test of the explosive, except in case of wide variation in results, when two or more additional samples are tested.

After each test the cork stopper of each tube is either discarded or carefully washed and dried and in any case is frequently renewed. The tube and the rod are carefully cleaned after each test, ether or other solvent being used to remove nitroglycerin, etc. They are then washed with water, and finally rinsed with distilled water. All the parts of the apparatus are dried in a steam oven at 100° C. The apparatus is at all times protected from laboratory fumes.

The tube is inserted to a depth of 2½ inches below the top of the bath, the water in the bath being within one-fourth inch of the top. The time of placing the tube in the bath is recorded, and the test is considered completed on the appearance of a brownish line at the lower edge of the moist portion of the paper, of the same intensity as the line on a standard-tint paper prepared as described below. It should be noted, however, that the brownish color on the test paper may at times be spread over a considerable portion of the paper, not forming a sharp, well-defined line. The operator should judge what would be equivalent to the standard tint over a width of one-half to 1 mm.

Caramel standard tint paper.[a]—The tint paper used as a standard color comparator for the test is made as follows: A solution of caramel in distilled water is prepared, of such concentration that when diluted to 100 times its volume (10 c. c. diluted to 1 liter) the tint of the solution equals that produced by the Nessler test on adding 2 c. c. of Nessler reagent to 100 c. c. of water containing 0.000075 gram of NH_3, or 0.0002305 gram of NH_4Cl. With a fine brush or pen dipped into this caramel solution fine lines are drawn on strips of filter paper (Schleicher and Schüll, 597). These strips are cut to the size of the regular test papers (1 inch by ⅜ inch) so that the brown line crosses each piece near the middle of its length. The line should be ½ to 1 mm. in width when dry. A piece of this standard tint paper should be placed in an empty tube beside those being tested, so that a comparison of color may be made.

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[a] 30th Ann. Report H. M. Inspector of Explosives, 1905, p. 236.

Preparation of test paper for Abel test.[a]—The paper used in preparing the test paper is Schleicher and Schüll's filter paper 597. This is cut in strips about 6 by 24 inches, and after being washed by immersing each strip in distilled water for a short time is hung up to dry overnight. The cords on which the paper is hung are clean and the room is free from fumes. The washed and dried paper is dipped in a solution prepared as follows:

The best quality of potassium iodide obtainable is recrystallized three times from hot absolute alcohol, dried, and 1 gram dissolved in 8 ounces of distilled water. Cornstarch is well washed by decantation with distilled water, dried at a low temperature, 3 grams rubbed into a paste with a little cold water, and poured into 8 ounces of boiling water in a flask. After being boiled gently for 10 minutes, the starch solution is cooled and mixed with the potassium iodide solution in a glass trough.

Each strip of filter paper is immersed in the above-mentioned mixture for about 10 seconds and is then hung over a clean cord to dry. The dipping is done in a dim light and the paper left overnight to dry in a perfectly dark room. Every precaution is taken to insure freedom from contamination in preparing the materials and from laboratory fumes that might cause decomposition. When dry the paper is cut into pieces about ⅜ by 1 inch and is preserved in the dark in tight glass-stoppered bottles, the edges of the large strips being first trimmed off about one-fourth inch to remove portions that are sometimes slightly discolored. When properly prepared the finished paper is perfectly white, any discoloration indicating decomposition due to contamination.

SAMPLING.

The first step to be taken in the analysis of dynamite, as with any other material, is the careful preparation of a sample. Dynamite is offered in commerce in the form of cylindrical "sticks" or cartridges, usually three-fourths inch to 1¼ inches in diameter and 8 inches long. For special work dynamite is made in cartridges up to 5 inches in diameter, but owing to restrictions in railroad transportation the length of cartridges of dynamite does not vary greatly, and cartridges over 8 inches long are unusual.

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[a] Storm, C. G., Proc. 7th Inter. Congress Applied Chem., 1909; Jour. Ind. and Eng. Chem., vol. 1, 1909, p. 802.

A cartridge of dynamite consists of a covering of paper, sometimes waxed or parchmentized and often coated with paraffin, within which the dynamite is more or less tightly packed to give it the density desired. In the manufacture of dynamite the paper "shell" is first made, and is then packed with the explosive, after which the cartridge is sometimes "redipped," by which is meant that the cartridge is plunged into a bath of paraffin heated slightly above its melting point. The paraffin closes any openings in the wrapper and tends to make the cartridge waterproof. This operation of "redipping" is of interest in connection with the analysis of explosives chiefly because of the opportunity it affords for the entrance of paraffin into the explosive. When a paper shell is not perfectly made some paraffin is apt to find its way through the paper shell and be absorbed by the wood pulp. In sampling, care should always be taken to remove any paraffin that has found access through the ends of the cartridge, since obviously such paraffin is not to be considered as a normal constituent of the explosive, and care should also be taken in unwrapping the cartridge to prevent scales and flakes of paraffin from becoming mixed with the sample.

The best method of sampling consists in opening the wrapper of each cartridge, spreading it out and cutting off from 3 to 5 cm. from each end of the roll of explosive thus exposed. These ends are rejected and the remainder carefully broken up to form a homogeneous mass. When a sample representing a large quantity of powder—for example, a day's output of a factory—is to be prepared, a number of cartridges are taken from different mixings, the central portions of each cartridge are selected in the manner described, and these portions are finely broken up in a large porcelain evaporating dish or on a sheet of paraffined paper. The mass is carefully stirred with a clean spatula, or is rolled from side to side upon the paraffined paper in the manner usually followed in preparing a sample of ore for assay. The stirring of the sample, or its rolling back and forth upon the paraffined paper, should occupy not less than five minutes, and the best results are obtained from such sampling when the explosive has been previously broken up to as fine a meal as possible by crumbling in the fingers or by gentle pressure with the spatula. A spatula suitable for this purpose is made of horn, or of wood saturated with paraffin so that it will not absorb nitroglycerin.

From the large sample prepared as described a sample of 50 to 100 grams is taken by selecting small portions from different parts of the mixed material, mixing these portions, and placing the mixture in the sample bottle.

In preparing a sample of dynamite there are several factors that must be constantly borne in mind. If a thoroughly mixed sample is prepared and allowed to remain for some time in a sample bottle, a segregation occurs, and the lower portions of the material in the sample bottle become richer in nitroglycerin at the expense of the upper portions. In some dynamites, particularly one that contains almost as much nitroglycerin as its absorbent base can hold, this change occurs rapidly, and may make a difference of several per cent in a few days. The tendency to segregate is greatest in a tall bottle, and is favored by warmth, the action taking place several times as rapidly at 30° C. as at 20° C. An indication of the amount of segregation that is possible in dynamite is seen from the results of the following experiment:

A sample of dynamite was prepared by carefully breaking up and sampling two sticks of 60 per cent dynamite, about 300 grams being taken and placed in an ordinary bottle of 250 c. c. capacity (diameter about 6 cm., height about 14 cm.). At the time the sample was placed in the bottle the analysis of the material gave the following results:

Analysis of 60 per cent dynamite.

[W. C. Cope, analyst.]

	Per cent.
Moisture	1.40
Nitroglycerin	60.60
Potassium nitrate	18.64
Calcium carbonate	1.25
Wood pulp	18.11

At the end of 10 days' exposure to a temperature of 32° to 33° C. (average, 32.5° C.) samples were taken from the top, middle, and bottom of the material in the bottle, and the following results were obtained:

Analyses of different parts of exposed sample of 60 per cent dynamite.

[W. C. Cope, analyst.]

Constituents.	Sample from top.	Sample from middle.	Sample from bottom.
	Per cent.	*Per cent.*	*Per cent.*
Moisture	1.25	1.16	1.17
Nitroglycerin	59.46	60.55	62.86
Potassium nitrate	19.91	18.44	17.42
Calcium carbonate	1.37	1.33	1.26
Wood pulp	18.01	18.52	17.29

Another experiment was made to illustrate segregation in cartridges themselves.

Whole cartridges of 40 per cent, 45 per cent, and 60 per cent dynamite were placed upright (on end) in a constant-temperature oven at 40° for a period of four weeks, the cartridges being supported by small wire tripods within glass cylinders. Pinholes were punched in the bottom of the wrappers to allow the escape of any accumulation of nitroglycerin, but no such leakage occurred.

At the end of four weeks samples were taken from the top and bottom of each cartridge, each sample representing about a 2-inch length of cartridge. The following results of analyses of these samples show the segregation of the nitroglycerin:

Analyses of parts of samples of dynamite left standing on end for four weeks at 40° C.

[J. H. Hunter, analyst.]

Grade of dynamite, per cent	40	45	60
Part of cartridge sampled.	Nitroglycerin.		
	Per cent.	*Per cent.*	*Per cent.*
Top	38.20	45.07	57.27
Bottom	40.96	47.98	63.26

From the above described experiments it will be seen that the sampling of dynamite involves problems not met in the preparation of ore for assay.

To determine any possible segregation due to nitroglycerin adhering to the dish in which a sample is mixed, 500 grams of dynamite was mixed in a large evaporating dish, and, when thorough mixing had been effected, was poured on a piece of paraffined paper. An analysis was then made of the large sample upon the paraffined paper, and the material adhering to the sides of the evaporating dish was removed by means of ether and analyzed. It was found that there was little difference between the composition of the two samples. It has been suggested that considerable changes in the moisture content of dynamite can occur during sampling, but this opinion does not seem correct. In the factory dynamite is usually mixed in an open mixer exposed to the atmosphere; consequently the percentage of moisture taken up or lost in the short length of time that the explosive is exposed to the air during sampling should be proportional only to the difference between the hygrometric condition of the air at the time the dynamite was made and that at the time it was sampled. To investigate this question further an experiment was made as follows:

Two cartridges of one-half pound (226 grams) each were mixed together quickly, and with as little exposure to the air as possible. This original sample was found to contain 1.10 per cent moisture.

A 100-gram portion of this large sample was then mixed on a large watch glass for 10 minutes on a damp day when the humidity of the air as determined by hygrometer readings was 75 per cent. Another 100-gram portion was similarly treated on a dry day when the humidity was only 19 per cent. Determinations of moisture were then made on these two portions with the following results:

Effect of exposure during sampling on moisture content of dynamite.

Treatment of sample.	Moisture.
	Per cent.
Without undue exposure	1.10
Stirred 10 minutes in moist atmosphere	1.25
Stirred 10 minutes in dry atmosphere	1.10

From these results it will be seen that the condition of the atmosphere has little effect on the moisture content of a sample when the sampling is done with reasonable dispatch and when atmospheric conditions are not abnormal.

CHEMICAL EXAMINATION.

QUALITATIVE EXAMINATION.

When no information is available as to the class to which an explosive to be analyzed belongs, a complete qualitative analysis is desirable, so that the proper methods of quantitative separation may be followed.

For the qualitative examination of a dynamite of any type a sample of 20 to 25 grams is most convenient. The sample is placed in a 1-inch test tube, which is then filled to about two-thirds of its depth with ether, stoppered, and well shaken. The ether is decanted through a filter paper and fresh ether is added to the tube. This treatment is repeated several times, and the residue is finally transferred to the filter and again washed with fresh ether. After the ether is drained off, the filter paper with its contents is removed from the funnel, spread out on a glass plate, and placed in a drying oven for a short time until nearly all the ether has evaporated. The dry residue is transferred from the filter back to the test tube, and is then ready for treatment with cold water, to remove the water-soluble constituents.

The ether solution is evaporated on a steam bath or electric heater at a low temperature until all odor of ether has disappeared. If the evaporation has caused the deposition of water in the beaker with the extract, this water is removed by placing the beaker in a vacuum desiccator for an hour or two. The presence of nitroglycerin is readily noted, the characteristic oily appearance of nitroglycerin and its viscosity serving to identify it. A convenient chemical test is to mix a drop of the heavy liquid, supposed to be nitroglycerin, with 1 or 2 c. c. of concentrated sulphuric acid in a test tube, and then to add about 1 c. c. of mercury. No stopper of any sort should be placed in the tube, but it should be shaken quickly from side to side so as to cause intimate contact of the mercury with the acid mixture. For 1 or 2 minutes little effect will be observed, but after a short time there will be noted, if the material under examination is nitroglycerin, the evolution of bubbles of gas from the liquid at the point where it comes in contact with the mercury, and the characteristic smell of nitrogen oxides will be noted. The nitric oxide (NO) produced is colorless, but upon coming in contact with the air it turns red or reddish-brown, forming nitrogen peroxide (NO_2). A simpler test for the presence of nitroglycerin, though by no means so satisfactory as the one just described, consists in taking up a small amount of the liquid in a capillary glass tube, and holding it cautiously in a flame. A strong detonation will result if the liquid is nitroglycerin. It is of course evident that there should be not more than a tiny fraction of a drop of nitroglycerin used in such a test, the best results being obtained when a very thin and small capillary is used, containing not more than 0.01 of a drop of the liquid tested.

If sulphur is present in the ether extract it will crystalize in needles or small granular masses in the residue upon the evaporation of the ether. The crystals of sulphur can be removed, washed free from nitroglycerin with a little acetic acid (70 per cent or glacial), after which they should be washed with water, dried, and heated over a flame. The odor of sulphur dioxide (SO_2) will identify the crystals as sulphur. Trinitrotoluene appears as long yellowish needles, which may be recrystallized from alcohol and identified by their melting point (80° C.), or by the color test with potassium or sodium hydroxide.[a] This color test is valuable as a means of identifying many of the nitrosubstitution products, although in a mixture the color produced by one constituent may completely hide the others. For example, the wine-red color obtained from trinitrotoluene may prevent the identification of other nitrocompounds that may be present. The test may be made directly on a portion of the ether extract, since the presence of nitroglycerin does not in any way interfere. The sample under examination is dissolved in 2 to 3 c. c. of acetone or methyl alcohol, and a few drops of 10 per cent potassium or sodium hydroxide added. The characteristic colors produced by various nitrosubstitution compounds are shown in the table following.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 599.

Color reactions of nitrosubstitution products with alkalies.

Substance.	Form.	Color of solution.	Result of addition of alk solution.
Mononitrobenzene	Liquid	Colorless	No effect.
Dinitrobenzene	Crystal	Faint yellow	Purple-rose, turning to claret.
Trinitrobenzene	do	Colorless to pale yellow.	Rich purple-brown.
Mononitrotoluene (ortho)	Liquid	do	No effect.
Mononitrotoluene (meta)	Crystal	do	Slight yellow.
Mononitrotoluene (para)	do	do	No effect.
Dinitrotoluene	do	do	Gradual evolution of a blue on standing.
Trinitrotoluene	do	do	Deep wine-red brown.
Mononitronaphthalene	do	do	No effect.
Dinitronaphthalene	do	Pale yellow	Reddish-yellow.
Trinitronaphthalene	do	do	Bright scarlet.
Tetranitronaphthalene	do	do	Reddish-yellow.
Picric acid	do	Golden-yellow	Precipitate of crysta potassium picrate (or

Rosin, vaseline, paraffin, oils, etc., are found in the extract, af evaporation of the ether, as a dark-colored, greasy mass on the su face of the nitroglycerin or adhering to the walls of the beak Small amounts of resins and oils are generally found in the extra from ordinary dynamite, these being normal constituents of th wood pulp, flour, or similar absorbents. The amount of such ma rials present is usually too small to be of any importance, and wh only small traces are found they may best be disregarded. If it desired to identify such materials the method for quantitati determination described later may be followed.

The water solution is examined for sodium, potassium, ammoniu zinc, the nitrate ion, etc. The qualitative and quantitative tests f these elements are discussed fully in all textbooks of analysis, an accordingly need not be repeated here. In ordinary qualitati work the writers have found the ring test for nitrates, with the us of the nitrometer in any doubtful case, to be most satisfactor potassium and sodium are best identified by the color they impa to the flame of the Bunsen burner, viewed through at least tw thicknesses of cobalt glass. The best test for ammonium is th evolution of ammonia by reaction with calcium oxide or sodiu hydroxide. Small quantities of iron, aluminum, chlorides, su phates, etc., are generally found in all dynamites as impurities fro the raw materials used.

The residue insoluble in water is treated with cold dilute hydro chloric acid; effervescence, if noted, is an indication of the presenc of a carbonate, and the usual tests are then made for CO_2. The aci extract after filtering is tested for calcium, magnesium, zinc, etc. whose carbonates or oxides may have been present in the powder as antacids.

The residue insoluble in water and dilute acid is best examined under the microscope, a magnification of 30 to 50 diameters being t convenient for all ordinary work. The identification of starch, al products, wood pulp, sawdust, kieselguhr, nitrocellulose, etc., is ussed in another part of this paper.

starch test is readily made by heating a portion of the mate- to boiling with dilute acid, cooling and adding a drop of iodine tion, this operation producing an intense blue coloration if rch is present.

DETERMINATION OF MOISTURE.

The moisture present in dynamite may be determined in the fol- ving ways:

(*a*) By drying in a desiccator over sulphuric acid, calcium chloride, other suitable drying agent without vacuum.

(*b*) By drying in a desiccator with vacuum.

(*c*) By passing dry air through the sample.

These methods have been carefully studied, and the first method, rying over sulphuric acid in a desiccator, has been found to have e widest application, and to be the most desirable in the analysis f explosives. In the determination of moisture in a sample of ynamite a number of important factors should be considered in rder that accurate results may be obtained. The weight of the ample, the manner in which the sample is spread upon the watch lass, the size and type of desiccator, the exposed area of the desic- ating agent, as well as its quantity and condition and the temperature at which the desiccation is carried out—all have an important bearing on the loss of weight resulting from desiccation, and unless care is taken moisture determinations made at different times on the same sample of dynamite will frequently give somewhat different results, owing to the slight variations in some of the above-named factors.

Preliminary studies were made to determine the amount of dynamite that is most suitable for the determination of moisture, and the thickness with which the sample should be spread upon the watch glass. The results of these tests showed that a sample of less than 2 grams of explosive is unsatisfactory, owing to the errors introduced, for example, by particles of material being carried away by the air during weighing, or upon opening the desiccator. When more than 2 grams of sample was taken the length of time required to effect thorough drying was unduly long; and consequently 2 grams of material, spread evenly on the concave surface of a 3-inch watch glass, was deemed the best amount for the determination. When only one or two analyses have to be run at a time, it is convenient to use a separate 5 or 6 inch desiccator for each sample, the bottom of the desiccator containing about 50 to 75 c. c. of concentrated sulphuric acid, and the watch glass being held by a triangle at a convenient and suitable distance above the acid. Objections have been raised[a] to the use of sulphuric acid as a desiccating agent in the determination of moisture in dynamite. The experience of the writers has shown these objections to be without grounds.

When a number of determinations are being made at the same time it is convenient to use larger desiccators, and the 10-inch size has been found to be satisfactory, five watch glasses being conveniently held at one time in such a desiccator.

IN ORDINARY DESICCATORS.

The period required for desiccation of a sample of dynamite in an ordinary desiccator is about 3 days or 72 hours. The first 12 hours within the desiccator reduces the moisture content to a very low percentage, but it has been found desirable to allow all samples to remain a further period of 60 hours, as the remainder of the moisture is slowly removed. The loss in weight, at the end of three days, of the 2-gram sample of dynamite on the watch glass is taken as moisture. After three days' drying, small amounts of moisture are still present, particularly in the wood pulp, but drying longer than three days has not been found desirable in ordinary analytical work. By long-continued desiccation, over either calcium chloride or sulphuric acid, a further gradual loss occurs which is evidently due to volatilization of nitroglycerin, and the amount of this loss varies with the temperature. Taking the loss of weight at the end of three days as representing moisture has been found to give uniform results in the case of dynamites of most varied composition, and has been adopted in the bureau's laboratory as a standard method, although it is impossible to say that at the end of any definite time all moisture has been removed from the sample and that further loss is due to volatilization of nitroglycerin.

Care should always be taken to spread the sample in a thin and uniform layer over nearly the entire surface of the watch glass, and the spreading should be done as quickly as possible to prevent undue exposure to the atmosphere. Experiments in which different sizes of desiccators (4-inch to 9-inch) were used showed that the rate of drying increased as the ratio of acid surface to powder surface increased, but that in three days the loss in all cases was practically the same. The effect of such variation is shown in the following table of results of tests of explosives containing amounts of moisture greater than that in ordinary dynamite. The table also shows a comparison between the efficiencies of two types of desiccators—the Scheibler, or ordinary type, which contains the acid in the bottom below the sample, and the Hempel type in which the acid is contained in the top or cover, above the sample. With an acid surface about 75 per cent as great as in the ordinary type the Hempel desiccator appears to be slightly more efficient than the Scheibler.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 382; Guttmann, O., Schiess- und Sprengmittel, 1900, p. 162.

Results of moisture determinations showing effect of variation in acid surface and in type of desiccator.

Type of desiccator		Scheibler.	Scheibler.	Hempel.
Size of desiccator		4-inch.	9-inch.	6-inch.
Area of acid surface (approximate)		7 square inches.	50 square inches.	38 square inches.
Name of explosive.	Time of drying.	Moisture content determined by loss of weight.		
	Hours.	*Per cent.*	*Per cent.*	*Per cent.*
Explosive A[a]	6	5.73	9.84	9.97
	12	8.82	10.11	10.29
	24	10.06	10.33	10.43
	48	10.52	10.63	10.65
	72	10.66	10.68	10.79
Explosive B[a]	2	1.89	....	3.18
	5	4.09	....	4.88
	24	5.34	5.50	5.51
	48	5.49	....	5.60
	72	5.50	5.59	5.63

[a] Arbitrary designation of sample.

The quantity of acid used in the desiccator must also be considered, because the dilution of the acid by the absorbed moisture is dependent upon the amount of acid present. In general, the acid contained in a desiccator does not require frequent renewal, and when from 50 to 75 c. c. of concentrated sulphuric acid (H_2SO_4) is used in the desiccator the renewal of this material once each month or once every two months is all that is necessary.

The following experiment illustrates the effect of dilution of the sulphuric acid by the absorption of considerable moisture from powder samples. Two samples of the same dynamite were desiccated in similar desiccators, one containing 75 c. c. of 96 per cent sulphuric acid, the other the same volume of 90 per cent sulphuric acid. In three days the losses of moisture were 1.10 per cent and 1.02 per cent, respectively, and in five days 1.17 per cent and 1.05 per cent, respectively. In order that 75 c. c. of 96 per cent acid could become diluted to 90 per cent by the absorption of moisture from dynamite samples it would be necessary that all of the moisture from about 460 2-gram samples of dynamite, each containing 1 per cent moisture, be absorbed by the acid. It is therefore obvious that the acid in the desiccators will not become diluted enough in one or two months to lose appreciably its affinity for moisture.

The effect of temperature on the moisture determination is shown in the following experiments, made with a 60 per cent dynamite. Three determinations of moisture were made on the same sample at widely different temperatures. Two grams of the sample in one desiccator were placed in an incubator, the temperature of which, by means of a thermostat, was regulated to a range of 36° to 38° C. (96.8° to 100.4° F.). A second desiccator containing another 2 grams of the sample was placed out of doors, the temperature varying during the experiment from −23° to 2° C. (−9.4° to 35.6° F.). A third desiccator containing a third 2-gram portion of the sample was left at room temperature, which varied from 17° to 25° C. (63° to 77° F.). In each of these experiments the 2-gram parts of the sample were spread upon 3-inch watch glasses, each watch glass being placed in a separate 4-inch desiccator containing 75 c. c. of fresh sulphuric acid. The results are tabulated below:

Results of tests to determine the moisture content of dynamite, showing the influence of temperature.

1	2			3	4	5		6	
Sample No.	Temperature.			Days exposed.	Loss of weight on desiccation.	Ether extract.		Nitroglycerin in ether extract.[a]	
	Maximum.	Minimum.	Mean.			By loss.	By direct weight.		
	°C.	°C.	°C.		*Per cent.*	*Grams.*	*Grams.*	*Grams.*	*Per cent.*
1	25	17	21	3	1.00				
				6	1.06				
				7	1.06				
				10	1.19				
				13	1.31	1.2158	1.2126	1.2051	60.26
2	38	36	37	3	1.69				
				6	2.49				
				7	2.74				
				10	3.54				
				13	4.12	1.1563	1.1522	1.1397	56.99
3	−7	−16	−9	3	0.60				
	−3	−23		6	....				
	0	−14		7	0.72				
	2	−9		10	0.67				
	20	18	19	13	1.03	1.2243	1.2220	1.2114	60.57

[a] Determined by nitrometer.

After the weighings had been made on the thirteenth day the samples were carefully transferred to Gooch crucibles, and extracted with ether in a Wiley extractor.[a] The crucibles were then dried at 100° C., and the losses in weight determined, which are given in column 5. The nitroglycerin in each sample of ether extract was then determined by the nitrometer after the ether had been evaporated (see p. 35). The results shown under "loss of weight by desiccation" (column 4) indicate the pronounced influence which temperature has on the determination of moisture. In the case of sample 2 most of the moisture was probably lost within the first 24 hours, the further loss being entirely due to the evaporation of nitroglycerin. In the case of the sample 3 the weight first taken, at the end of three days, showed a loss of only 0.60 per cent. As previous experiments had shown that this amount of moisture can be removed from 60 per cent dynamite by about two hours' desiccation, it is probable that the loss noted during the first three days resulted during the first two hours' desiccation, before the sample became frozen. Practically no further loss occurred in this sample up to 10 days, and the loss which occurred between the tenth and thirteenth day was due to the fact that the sample had thawed. As the temperature in the laboratory frequently reaches 35° C. or more during the summer, it is evident that abnormally high results sometimes obtained during warm days of summer may be in error to a considerable extent, being only in part due to loss of moisture and in part to volatilization of nitroglycerin. Since incorrect results are obtained when moisture is determined at a low temperature, no determinations of moisture should be made at a temperature sufficiently low to cause the sample to freeze. In order that perfectly uniform results may be obtained with samples of dynamite, the temperature of the room in which the desiccation is carried out should be practically constant at 20° C. This is a normal working temperature, and when moisture determinations are made at temperatures materially above or below it, allowance should be made for the influence of the abnormal temperature. The results given in the table on p. 22 are shown in the form of curves in figure 1. The curve for sample 3 represents the results

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[a] For the method used in the extraction see p. 30.

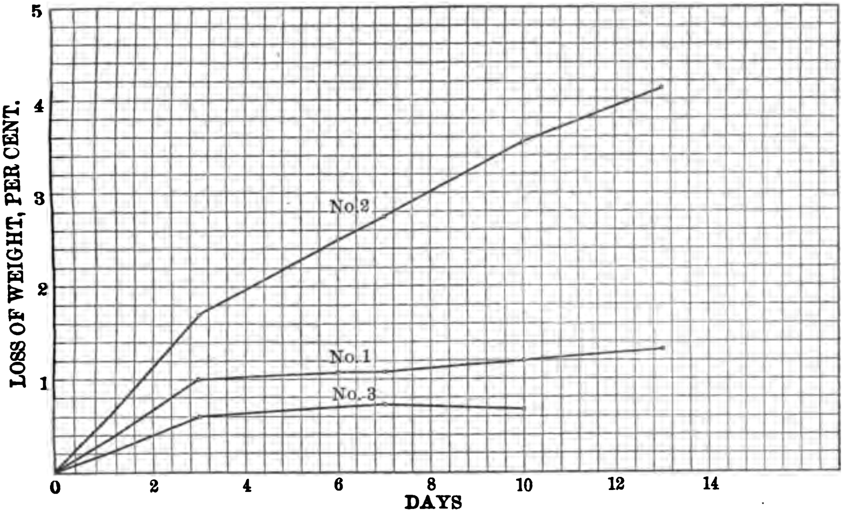

Figure 1.—Influence of temperature on determination of moisture in 60 per cent dynamite by desiccation over sulphuric acid. Temperature (mean): No. 1, 21° C.; No. 2, 37° C.; No. 3, —9° C.

of the first 10 days' exposure, during which period the sample remained frozen.

In the determination of moisture by the bureau's explosives laboratory, sulphuric acid has been accepted as the standard desiccating agent. As many chemists prefer to use calcium chloride, the following experiment is of interest, as showing the difference in efficiency of these two desiccating agents. Six 2-gram samples of 60 per cent dynamite were weighed from a large, well-mixed sample. Three of these samples were desiccated over calcium chloride and three over sulphuric acid. An individual 6-inch Scheibler desiccator was used for each sample. Weighings made at intervals showed the loss of moisture as follows:

Results of desiccation of 60 per cent dynamite over calcium chloride and over sulphuric acid, at room temperature.

Time.	Designation of sample.	Loss of weight over calcium chloride.	Designation of sample.	Loss of weight over sulphuric acid.
Days.		*Per cent.*		*Per cent.*
$\frac{1}{12}$	A	0.50	C	0.64
$\frac{1}{4}$	A	.59	C	.73
$\frac{1}{2}$	A	62	C	.79
$\frac{3}{4}$	B	.66	D	.87
1	A	.67	C	.84
2	B	.77	D	.94
3	A	.77	C	.96
3	B	.80	D	.97
3	E	.84	F	1.02
5	A	.84	C	1.01
5	B	.87	D	1.01
5	E	.91	F	1.07
6	A	.84	C	1.02
6	A	.87	D	1.05
6	E	.93	F	1.10
10	A	.95	C	1.11
10	B	1.00	D	1.17
10	E	1.00	F	1.20
13	A	1.07	C	1.23
13	B	1.10	D	1.32
13	E	1.15	F	1.36
16	A	1.16	C	1.33
16	B	1.13	D	1.46
16	E	1.25	F	1.48
19	E	1.25	F	1.53
20	E	1.37	F	1.60
34	E	1.72	F	2.01
50	E	2.22	F	2.55
75	E	2.82	F	3.35
111	E	3.67	F	4.55
183	E	5.77	F	7.55
237	E	6.85	F	9.20

These results, plotted in the form of curves for the two samples E and F, upon which desiccation was continued the longest, are shown in figure 2.

The fact that nitroglycerin is more or less volatile even at ordinary temperatures is recognized by most explosives chemists, and in some laboratories an endeavor is made to avoid loss of nitroglycerin during desiccation by keeping the atmosphere within the desiccator saturated with nitroglycerin vapors. This is done by placing in the desiccator, together with the sample of dynamite on which moisture is to be determined, a quantity of nitroglycerin on a watch glass, it being assumed that the evaporation of this nitroglycerin will saturate the atmosphere in the desiccator and minimize the loss of nitroglycerin from the sample of dynamite.

To test the value of such method the following experiments were made: Four samples (2 grams each) of the same 60 per cent dynamite used above were spread on 3-inch watch glasses and placed in separate desiccators. Directly underneath each of the watch glasses was placed a watch glass containing a layer of fine dry sand saturated with nitroglycerin. Two of the desiccators contained sulphuric acid and two calcium chloride. Weighings of the dynamite samples at intervals showed losses of weight as follows:

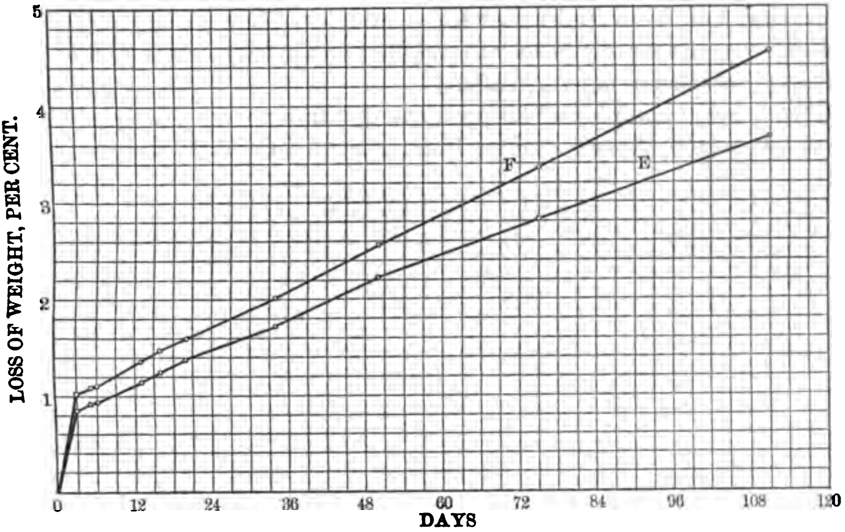

FIGURE 2.—Results of desiccation of 60 per cent dynamite over calcium chloride (E) and over sulphuric acid (F) at room temperature.

Results of desiccation of 60 per cent dynamite over calcium chloride and over sulphuric acid in an atmosphere saturated with nitroglycerin vapors.

Designation of sample.	Desiccation over calcium chloride.		Designation of sample.	Desiccation over sulphuric acid.	
	Time.	Loss of weight.		Time.	Loss of weight.
	Days.	*Per cent.*		*Days.*	*Per cent.*
A	3	0.77	C	3	....
B	3	.80	D	3	0.92
A	6	.93	C	6	1.10
B	6	.97	D	6	1.12
A	10	1.02	C	10	1.13
B	10	1.00	D	10	1.15
A	13	1.15	C	13	1.20
B	13	1.17	D	13	1.25
A	19	1.25	C	19	1.31
B	19	1.35	D	19	1.40

Comparing these results with those of the table on page 24, it will be noted that the placing of an additional amount of nitroglycerin in the desiccator with the sample of dynamite has practically no effect on the amount of nitroglycerin lost from the sample.

The fact that nitroglycerin volatilizes in the desiccator in the presence of either sulphuric acid or calcium chloride suggested the carrying out of experiments to determine whether a sample of dynamite that had been desiccated for a sufficient time to lose all of its moisture would continue to lose weight in an empty desiccator (without any desiccating agent present).

Two 2-gram samples of 60 per cent dynamite were dried for three days on watch glasses over sulphuric acid, and then immediately placed in clean desiccators without any drying agent. One of these was kept at room temperature (17° to 22° C.), the other in a constant-temperature incubator oven at a temperature of 33° to 35° C. Weighings made at intervals showed a continued steady loss from the sample at 33° to 35°, whereas the sample exposed to room temperature gained in weight at first, then steadily lost until at the end of about 40 days it had attained its original weight. In the table below the percentage of loss or gain in weight recorded represents the variation from the dry weight of the samples after having been desiccated three days.

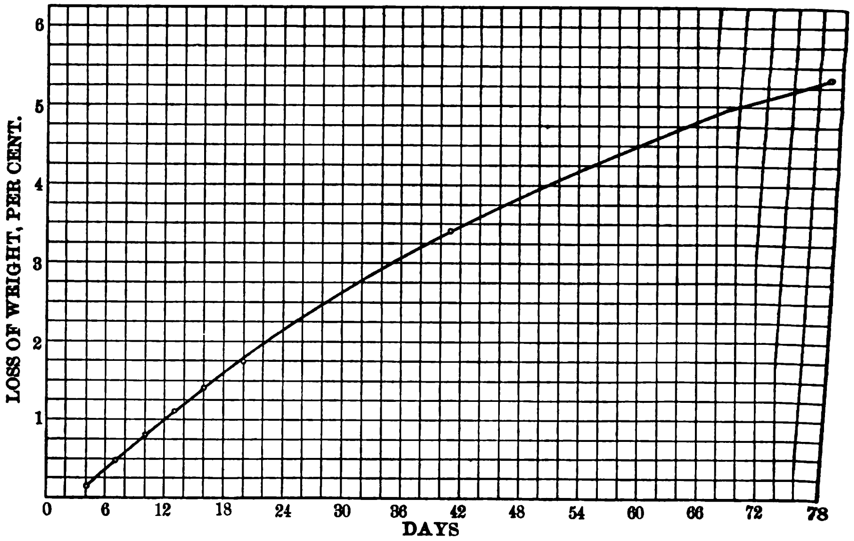

FIGURE 3.—Result of exposure of dry 60 per cent dynamite in a desiccator at 33° to 35° C. without desiccating agent.

Change in weight of dried samples of 60 per cent dynamite in desiccators containing no desiccating agent.

Time in desiccator.	Change in weight.		
	Sample *A* (17°-22° C.).		Sample *B* (33°-35° C.).
	Gain.	Loss.	Loss.
Days.	*Per cent.*	*Per cent.*	*Per cent.*
4	0.36	....	0.13
7	.35	....	.46
10	.30	....	.80
13	.25	....	1.10
16	.20	....	1.40
20	.20	....	1.75
41	....	0.05	3.40
77	....	.67	5.35
202	....	2.63	9.33

It is often desirable to make a weighing at a shorter interval than 72 hours, and to obtain an approximation of the true moisture by calculation. An extended series of tests was made to determine what factor could be safely used, in conjunction with a weight taken at the end of 24 hours, to give the same result as would be obtained by desiccation for a period of 72 hours. It was found that the influence of the temperature of the room in which the desiccator was kept was so marked, and the difference in effect between different desiccating agents,[a] was such as to make this method uncertain. At the best only an approximation can be obtained, but when time is more important than accuracy a rough approximation to the true moisture content of ordinary dynamite can be obtained by considering the loss in weight over sulphuric acid in 24 hours to be 90 per cent of the total moisture. In other words, the loss of weight in 24 hours' desiccation multiplied by the factor 1.11 will be an approximation to the true moisture content. When large amounts of moisture are present, as in certain types of coal-mining explosives containing water added as a constituent of the explosive, it is not advisable to attempt the use of such a factor. In such cases the loss of weight on desiccating three days is considered as the total moisture.

IN VACUUM DESICCATORS.

The evaporation of water is much more rapid at reduced pressure than under atmospheric pressure, and therefore the determination of moisture may be made in a shorter time with the use of a vacuum than when atmospheric pressure prevails within the desiccator. If nitroglycerin were perfectly nonvolatile, desiccation in a vacuum would probably be sufficiently reliable for use as a standard method.

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[a] See table on p. 24.

The following table shows the results obtained when samples of the same dynamite were exposed in desiccators of similar size and shape that contained the same desiccating agent, in one case a vacuum being used and in the other case the air within the desiccator being at the pressure of the air in the room.

Results of desiccating tests with and without vacuum in the desiccator.

Time dried.	Sample in ordinary desiccator.	Sample in vacuum desiccator.
	Per cent.	*Per cent.*
Loss of moisture in 24 hours	5.34	5.42
Loss of moisture in 48 hours	5.49	5.63
Loss of moisture in 72 hours	5.68	5.80

With the ordinary type of desiccator, containing acid in the bottom, moisture is removed from the sample much more rapidly with a vacuum than without, other conditions being equal. For example, in a 4-inch desiccator, with 7 square inches of acid surface on which the pressure was that of the atmosphere, the loss of moisture from a powder sample containing about 11 per cent of water was only 54 per cent of the total in 6 hours, 83 per cent in 12 hours, and 94 per cent in 24 hours. In a slightly larger desiccator of the same type, with 12 square inches of acid surface, above which there was a vacuum, the loss in 6 hours was 91 per cent, in 12 hours 95 per cent, and in 24 hours 96.5 per cent. In both samples a practically constant value was obtained in 3 days.

In the case of the Hempel desiccator, containing acid above the explosive sample, the rate of loss of moisture is nearly the same with or without vacuum.

In general it may be stated that any type of vacuum desiccator will remove in 12 hours practically all the moisture from dynamites and even from permissible explosives containing as much as 10 to 12 per cent of water, the result thus obtained being about the same as that given by 3 days' desiccation without vacuum.

Vacuum desiccation for a longer time than 12 hours will cause a further slight loss, which is probably for the most part due to volatilization of nitroglycerin.

IN A DRY-AIR CURRENT.

When a current of air previously dried by being passed through a calcium chloride tube, or through sulphuric acid, is passed through a mass of dynamite in a suitable sample tube, the dynamite gives up its moisture to the dry air. Drying may be very quickly effected in this manner, because of the fact that the dry air comes into intimate contact with all portions of the explosive, but the method has the serious defect of being inaccurate, owing to the volatility of nitroglycerin.

In desiccation by means of dry air, a drying tube of the form shown in figure 4 is usually employed. Sometimes several of these tubes are connected together in a train. The dry air is always introduced at the bottom, so that it may rise through the explosive, and a weighed sample of about 15 grams is generally taken for the determination.

Several tests were made to determine the accuracy of this method of drying samples of dynamite. A current of air dried by passing through sulphuric acid was passed through a sample of dynamite which had been found, by desiccation for three days over sulphuric acid, to contain 5.68 per cent of moisture. Weighings at intervals showed loss of weight as follows.

Loss of weight of dynamite in a current of dry air.

Time dried.	Loss of weight.
Hours.	*Per cent.*
2	1.47
6	4.29
12	5.20
24	5.50
48	5.70
60	5.80
72	5.86

The table shows that at the end of 48 hours there had been a loss in weight approximately corresponding to the percentage of moisture found in the explosive by the standard method. The constant loss after that point represents volatilization of nitroglycerin, although it is of course to be noted that the loss of nitroglycerin was continuous, nitroglycerin being removed from the time the air first began to pass through the sample. How inaccurate this method is may be readily understood when one remembers that nitroglycerin can be completely volatilized by bubbling dry air through it for a sufficient length of time, and that accordingly any sample of dynamite would probably reach an ultimate value in which the loss in weight would correspond to the amount of moisture plus the amount of nitroglycerin present in the sample.

SUMMARY.

The most satisfactory method for the determination of moisture consists in using a 3-inch watch glass containing an evenly distributed 2-gram sample, the watch glass and sample being placed in a desiccator containing sulphuric acid, and being weighed at the expiration of 72 hours. Care should be taken that the temperature does not vary widely from a mean of 20° C. An approximation of the true moisture content of the sample of explosive may be obtained by desiccating in the manner just described for a period of 24 hours, and multiplying the loss in weight thus found by the factor 1.111, or the loss in a vacuum desiccator for 24 hours may be taken without further calculation as an approximation to the true moisture content as determined by standard methods.

EXTRACTION WITH ETHER.

Extraction with ether removes from dynamite not only nitroglycerin, but also any resins or sulphur that may be present. Aside from resin intentionally admixed there is always some resin present in the wood pulp. In addition to these constituents, in dynamite small amounts of oil are sometimes found, having been introduced from mixing machines or packing machines. When flour, corn meal, or other grain or cereal products are present as constituents of explosives a small amount of oil from such materials is also found in the ether extract. Nitrotoluenes, paraffin, vaseline, etc., are not normal constituents of ordinary dynamite, and the determination of these substances is discussed under the type of explosive in which they occur as characteristic components, but it is to be noted that were any of these materials present in dynamite they would be found in the ether extract.

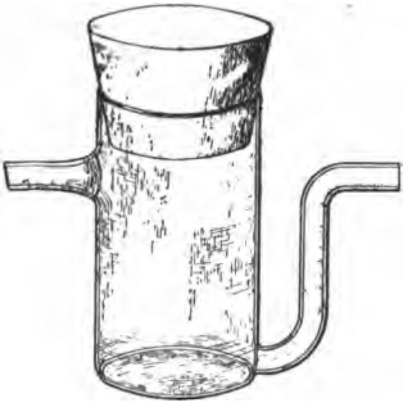

FIGURE 4.—Drying tube.

REFLUX-CONDENSER METHOD.

A sample of from 6 to 10 grams of the explosive is weighed in either a porcelain Gooch crucible with asbestos mat or a porous alundum[a] crucible of about 25 c. c. capacity. When a Gooch crucible is used the mat should be light, but should be perfectly coherent. Such a mat is prepared in the bureau's explosives laboratory as follows: Five grams of short-fiber asbestos, in the form of short shreds, free from hard lumps, is added to 1 liter of water. When used the mixture is well shaken and about 10 c. c., an amount sufficient to fill the crucible to about two-thirds of its depth, is poured into the crucible. Suction is applied, and a smooth and perfect mat is almost invariably produced. The crucible and mat are then carefully dried for some hours at 100°, weighed, and placed in a desiccator. For extracting with ether, the form of apparatus found most satisfactory is the

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[a] A trade name for artificially prepared porous aluminum oxide.

Wiley extractor, as shown in Plate II, *A*. The crucible is supported on a small hanger made by twisting No. 18 copper wire into suitable shape.

In performing an extraction the crucible, with its weighed sample of explosive, is placed in the hanger, and about 35 c. c. of U. S. P. ether (96 per cent) is poured in several portions through the sample into the glass extraction tube. Water is continuously circulated through the cooling coils of the condenser. The ether is boiled by means of an electric heater or a vessel of hot water in which the lower part of the tube is immersed. The ether vapor condenses on the surface of the metal condenser, the condensed ether dropping into the crucible and percolating through the sample of explosive. The temperature is regulated so that the sample will be kept covered with ether without any overflow.

When a vessel of hot water is used for heating the tube, the ether partly drains out of the crucible during a change of water, but is at once replaced by a fresh supply. This intermittent action probably accomplishes a more efficient extraction than is obtained by keeping the sample continuously covered with ether. The extraction with ether is continued for about three-fourths of an hour for most explosives. This period is usually somewhat longer than is necessary to remove all of the nitroglycerin, but it is desirable to carry on the extraction long enough to insure the complete removal of material soluble in ether, so as to avoid testing for completeness of extraction. If for any reason a shorter time for extraction is desirable, the extraction is continued for the time desired, after which a small additional amount of ether is put into the apparatus, and the ether passing through the crucible is evaporated in a watch glass and an examination made for residue. If residue is found, complete extraction has obviously not been accomplished.

The crucible containing the portion of the explosive insoluble in ether is placed in a drying oven heated to about 100° C. This should be done promptly, since the evaporation of the ether with which the contents of the crucible are saturated lowers the temperature of the crucible sufficiently to cause the precipitation of considerable moisture upon the crucible and its contents, and such a precipitation is undesirable as it necessitates longer drying. Although no loss or inaccuracy in analysis is liable to result from the constituents of the explosives becoming wet at this stage, yet for uniform results in drying it is usually best to transfer the crucible directly from the Wiley extractor to the drying oven. To avoid filling the drying oven with ether vapors, it is convenient to have a suction flask and carbon tube near the Wiley extractor, and as soon as the ether extraction is completed the crucible, still very wet with ether, may be placed in the carbon tube and sucked dry, after which it is placed in the drying oven.

If the qualitative examination has indicated the presence of ammonium nitrate, the drying of the material insoluble in ether should be carried out at 70° C. instead of 100° C., because at 100° an appreciable loss of ammonium nitrate results whereas at 70° the loss is slight.

The periods of drying generally adopted are five hours at 95° to 100°, and overnight or 18 to 24 hours at 70° C. Even at the higher temperature no error results by drying overnight unless ammonium salts or other volatile ingredients are present. A shorter time than five hours is probably sufficient in most cases, but the five-hour period has been adopted to cover all cases and obviates any necessity of an additional check weighing.

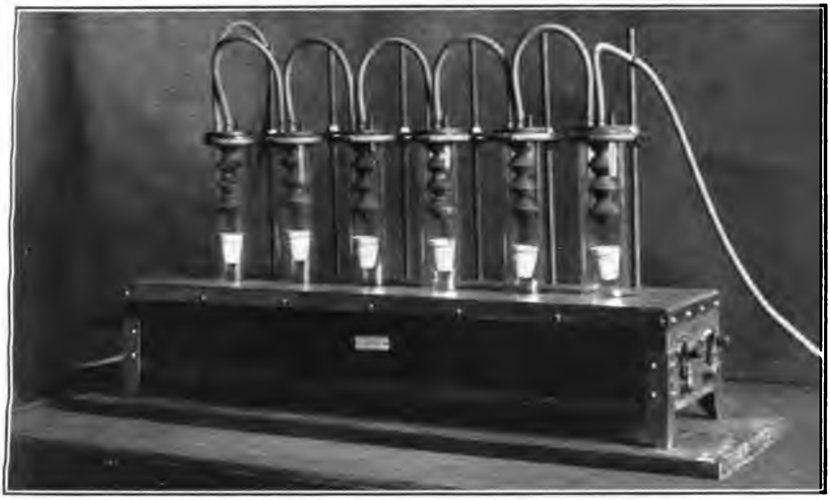
The loss of weight represents all ether-soluble material plus the moisture originally present in the sample.

The ether extract is transferred from the glass extraction tube to an evaporating dish of low pattern or to a small beaker previously weighed. The extraction tube is then washed out with a small quantity of pure ether, which is added to the ether extract in the evaporating dish. The contents of the evaporating dish are allowed to evaporate spontaneously; a number of hours are usually allowed for the evaporation, the best results being obtained when the period is overnight. After the ether has evaporated, the residue is thoroughly dried by leaving the dish for a few hours in a vacuum desiccator. The weight is then noted; it is usually a little less than the total loss on ether extraction minus the moisture as determined by desiccation. The difference is due to volatilization of the nitroglycerin during the evaporation of the ether, and is considered later.

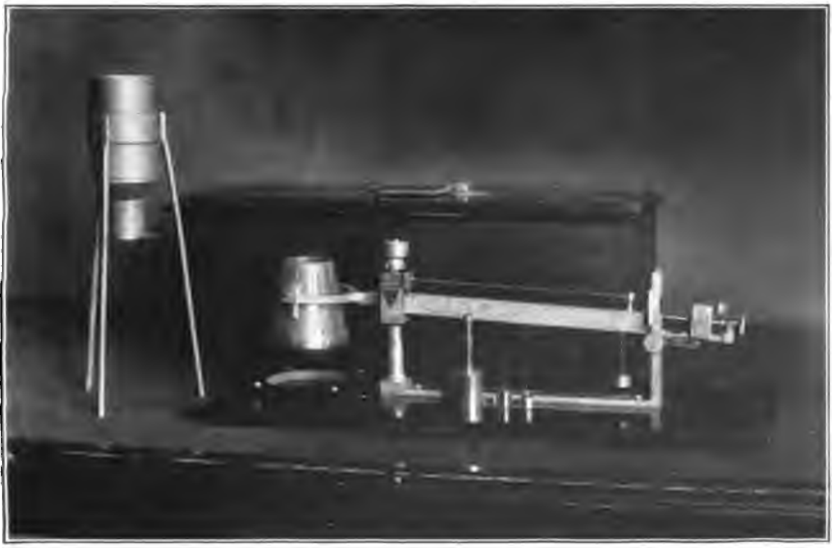
A more nearly correct value for the weight of material removed by ether is obtained by deducting the amount of moisture determined by desiccation from the total loss of weight found by extraction, the direct weight of the ether extract after the evaporation of ether being used only as a check. In all cases ether extraction should be made in duplicate, one sample of the weighed extract being used for the determination of the nitroglycerin with the nitrometer, and the other sample being used in determining the other constituents present.

SUCTION METHOD.

In the laboratories of some dynamite works extraction with ether is made without any form of continuous-extraction apparatus; the sample in the Gooch crucible is merely washed several times by pouring ether through it, applying suction after each addition of ether. This method involves the use of greater quantities of ether,



A. APPARATUS FOR ETHER EXTRACTION. WILEY EXTRACTOR.



B. GRAVIMETRIC BALANCE.

and the objection has been made that the reduction of temperature resulting from the evaporation of ether causes a deposition of moisture from the air current drawn through the sample, this moisture dissolving out small amounts of the water-soluble nitrates that pass through with the next addition of ether.

To test the merits of this method in comparison with the usual extraction method, ether extractions were made on a large number of samples of 45 per cent dynamite, using both the reflux-condenser method and the suction method. In the latter method about 100 c. c. of ether in six portions was passed through each sample, each portion of ether being allowed to stand in the crucible for one minute before suction was applied. The suction was continued for periods of one-half minute to two minutes in order that different amounts of air might be drawn through the samples. The samples were then dried and weighed as usual.

In general, extraction in the Wiley apparatus gave slightly lower results than the suction method, although in most cases the difference between duplicate samples extracted by the same method was as great as the variation between the two methods. This fact is explained by the lack of homogeneity of the dynamite. For example, a few unusually large particles of wood pulp or nitrate in one sample may cause a greater variation in the percentage of ether extract than the variation actually due to the method of extraction employed.

COMPARATIVE EXTRACTIONS WITH ANHYDROUS AND U. S. P. (96 PER CENT) ETHER.

To ascertain the effect of the purity of the ether used for extractions, determinations of ether extracts were made on several types of explosives, and on various carbonaceous absorbents used in dynamites. Duplicate determinations were made using both anhydrous ether (distilled over sodium) and U. S. P. (96 per cent) ether.

Results of extractions are shown in the following table, the values given being the percentage of loss of weight noted on weighing the insoluble portion after drying five hours at 95° to 100°. The loss of weight in each case therefore includes any moisture originally present.

Loss of weight of explosives and of carbonaceous absorbents by ether extraction.

Kind of sample.	Kind of ether.	
	U. S. P. (96 per cent).	Anhydrous.
	Per cent.	*Per cent.*
Dynamite (A)	25.86	25.69
Dynamite (B)	32.58	32.51
Dynamite (C)	40.77	40.74
Corn meal	14.81	14.92
Wheat flour	13.18	13.12
Wheat middlings	14.91	14.78
Corn meal, dry	1.81	1.71
Wood pulp, dry (1)	2.71	2.18
Wood pulp, dry (2)	2.59	2.20
Wood pulp, dry (3)	2.31	1.85
Wood pulp (4)	8.84	8.02
Wood pulp (5)	5.44	4.73
Wood pulp (6)	5.98	5.48
Wood pulp (7)	12.24	11.98
Wood pulp (8)	13.30	12.75
Wood pulp (9)	5.65	5.23
Wood pulp (10)	6.23	5.88
Wood pulp (11)	5.01	4.85
Wood pulp (12)	7.74	7.40
Wood pulp (13)	8.27	7.86

From the table it is apparent that U. S. P. ether extracts a larger percentage of material from the commonly used carbonaceous absorbents than does anhydrous ether, which is practically free from alcohol. It is probably because of the alcohol present, in amounts up to about 4 per cent, that U. S. P. ether shows the greater extractive power.

EFFECT OF MOISTURE IN DYNAMITE ON EXTRACTION WITH ETHER.

Numerous authorities prescribe that the ether extraction shall be made on a sample previously dried to constant weight in a desiccator.[a] Presumably this specification is aimed to prevent water-soluble constituents from being carried through in the ether extract. Such an error is naturally greater as the amount of moisture present in the dynamite is greater. Accordingly experiments were made on mining explosives similar to ordinary dynamite, to which water had been added as an additional constituent for the purpose of reducing the temperature of explosion. Two explosives containing 10.70 and 5.70 per cent of moisture, respectively, were extracted with ether in the usual manner, (1) in the original condition, and (2) after having been dried in vacuum desiccators over sulphuric acid for 24 hours. The amounts of materials soluble in ether extracted are shown in the following table.

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[a] Guttman, O., Schiess-und Sprengmittel, 1910, p. 162; Kedesdy, E., Sprengstoffe, 1909, p. 247; Escales, R., Die Explosivstoffe, vol. 3, 1908, p. 204.

Results of ether extraction of two explosives in different conditions.

1	2	3	4	5
Sample.	Condition.	Moisture.	Extract.	Difference.
		Per cent.	*Per cent.*	*Per cent.*
A	1	10.70	26.52	0.59
	2	.44	[a] 25.93	
B	1	5.70	25.79	.36
	2	.45	[a] 25.43	

[a] Calculated to explosive in original condition.

The amount of moisture present in the dried samples was found by desiccating portions of each sample for a further period of three days in ordinary sulphuric-acid desiccators.

The values in column 4 represent the total loss on extraction less the moisture content of the sample, all results being expressed as a percentage of the amount of original undried explosive.

Assuming that the extracts from the samples in their original condition (condition 1) are larger than those from the dried samples (condition 2) because of loss of water-soluble nitrate in the moisture taken up by the ether, it is apparent that in the case of ordinary dynamite containing only one or two per cent moisture any loss from this source is negligible.

DETERMINATION OF NITROGLYCERIN.

The nitrogen of organic or inorganic nitrates or nitrites is readily evolved as nitric oxide (NO) by reaction with sulphuric acid and mercury in the nitrometer. A determination of such nitrogen in the extract therefore serves as a means of calculating the amount of nitroglycerin present. The form of nitrometer found by the authors to be most satisfactory for explosives work is the modified Lunge nitrometer, as illustrated in Plate III.

THE NITROMETER.

This instrument [a] consists of six glass parts as follows: A globe-shaped reservoir (*a*); a generating bulb (*b*) of about 300 c. c. capacity, the generating bulb having stopcocks at both top and bottom to permit a violent agitation, and having a cup above which communicates with the bulb through the upper stopcock; a second globe-shaped reservoir (*c*), to which, by means of a glass multiple connecting tube and rubber tubing, are joined a compensating burette (*d*), a reading burette (*e*), and an additional measuring burette (*f*). The reading and compensating burettes are of the same shape and size, and are blown out into bulbs at the top. The compensating burette is not graduated. Above the bulb it has a small vertical open tube, which is sealed when the instrument is standardized. The reading burette is calibrated so that percentages of nitrogen may be read therefrom, and is marked to read from 10 to 14 per cent, being graduated to one-hundredths of 1 per cent. Between 171.8 and 240:4 c. c. of gas must be generated to obtain a reading; that is, the 10 per cent mark represents the volume of 171.8 c. c. of NO at 20° and 760 mm. pressure, containing 0.1 gram of nitrogen; the 14 per cent mark is equal to 240 c. c. NO under the same conditions, representing 0.14 gram nitrogen.

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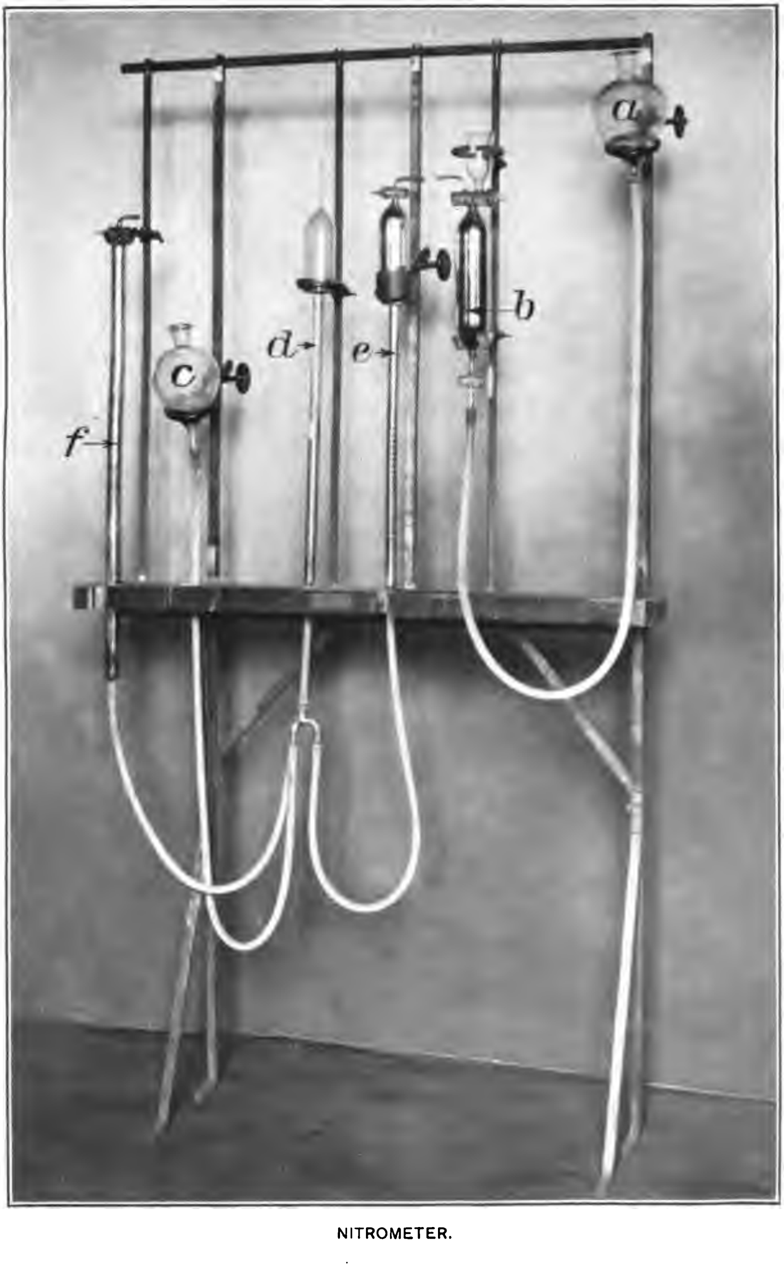
[a] The description has been taken in a large part from a paper by J. R. Pitman on The analysis of nitric and mixed acids by du Pont's modification of the Lunge nitrometer, Jour. Soc. Chem. Ind., vol. 19, 1900, p. 983; see also Lunge, G., Du Pont's nitrometer, Jour. Soc. Chem. Ind., vol. 20, 1901, p. 100.

The compensating burette is supported by a ring; the generating bulb is supported just above each stopcock by forked holders, curved so as to retain the bulb in place. In order to remove the generating bulb it needs only to be raised slightly and brought forward, the manipulation of a screw, as with an ordinary clamp, being thus avoided. The two reservoirs and the reading burette are supported by ring clamps, these clamps having milled rollers at the shank; they are moved up and down vertical racks by means of hand screws, the rollers being so arranged in conjunction with the vertical racks that the weight of the part presses them down and acts as a brake, thus preventing their moving when not being manipulated.

Having arranged the apparatus and filled the compensating, reading, and generating tubes as well as their connections with mercury, the next step is to standardize the instrument. Twenty to thirty cubic centimeters of sulphuric acid is run into the generating bulb through the cup at the top, and at the same time about 210 c. c. of air is let in; the cocks are then closed and the bulb is well shaken; this shaking thoroughly desiccates the air, which is then run into the compensating burette until the murcury is about on a level with the 12.50 per cent mark on the reading burette, the two burettes being held at the same height. The compensating burette is then sealed off at the top. A further quantity of air is desiccated in the same manner and run over into the reading burette until the height of mercury in the reading burette stands at about the 12.50 per cent mark. The cocks are then closed, and a small piece of glass tubing, filled with sulphuric acid (not water), and bent in the form of a U, is attached to the outlet of the reading burette. When the mercury columns are about balanced and the inclosed air has been cooled to room temperature, the cock is again carefully opened, and when the sulphuric acid balances in the U tube, and the mercury columns in both burettes are therefore at the same level, the air in each tube is subject to the same conditions, namely, atmospheric temperature and pressure. A reading is now made from the burette,



NITROMETER.

and the barometric pressure and temperature are carefully noted. Using the well-known formula

$$V=\frac{V'P'(273+t)(1-.00018t')}{P(273+t')(1-.00018t)}$$

the volume this inclosed air would occupy at a pressure (P) of 29.92 inches of mercury (760 mm.) and at a temperature (*t*) of 20° C. is determined. The cock is again closed and the reservoir and reading burette carefully adjusted so as to bring the air in the reading burette to the calculated volume and the mercury in the compensating burette to the same level as the mercury in the reading burette. A strip of paper is now pasted on the compensating burette at the level of the mercury, and the standardization is then complete.

There is, however, another and shorter method of standardization than the one described above. It is well known that the quality of the sulphuric acid used in the nitrometer will materially affect the results. To ascertain whether sulphuric acid is suitable for use in making nitrogen determinations in the nitrometer a determination is made on chemically pure dry potassium nitrate and the reading obtained in the nitrometer is compared with the theoretical percentage of nitrogen in potassium nitrate. In applying this procedure to the standardization of the nitrometer the compensating burette is filled with desiccated air, as described above, and 1 gram of potassium nitrate, dissolved in 2 to 4 c. c. of water, is introduced into the generating bulb, the cup is washed with 20 c. c. of 95 to 96 per cent sulphuric acid in three or four portions, and each portion is run separately into the bulb. The gas, when generated, is run over into the reading burette, and the mercury columns in both burettes are leveled, so that the mercury in the reading burette is also at 13.87, the theoretical percentage of nitrogen in potassium nitrate. A strip of paper is pasted on the compensating burette at the level of the mercury, and the standardization is then accomplished.

This method of standardizing offers many advantages over that first described, among which may be mentioned that no readings of temperature or pressure are necessary. Probably the greatest advantage is that if the acid used in standardizing should contain impurities, which might otherwise affect the result, the error is entirely compensated and corrected in subsequent work; that is to say, the instrument having been so standardized that the reading gives the theoretical percentage of nitrogen in potassium nitrate, the results will be accurate when testing other substances so long as the same quantity of sulphuric acid from the same lot is used.

It must, of course, be understood that once having standardized the instrument with a certain lot of acid no different lot of acid can be used without restandardizing. In order to avoid slight differences in results due to variations in the acid, it is advisable to reserve a sufficiently large uniform stock of acid, for example, a carboy full, for nitrometer use.

The additional measuring burette, with which this type of nitrometer is provided, known as the "universal tube" (*f*, Pl. III), is simply a straight burette, marked to read from 0 to 100 in percentages and graduated to one-tenth of 1 per cent. The tube is of such a size that 0.30 gram of NO (or $\frac{1}{100}$ gram-molecule of NO) under standard conditions of temperature and pressure (20° and 760 mm.) fills it to the 100 mark.

If it is desired to read the percentage of nitrogen direct, 0.14 gram of substance is weighed out; if the percentage of NO_2 is desired, 0.46 gram of substance is weighed out. Consequently, if 1.01 grams of potassium nitrate, 0.63 gram of nitric acid, or 0.85 gram of sodium nitrate are used, the results can be read directly as percentages of the original substance.

This method is convenient when it is not certain that the reading will fall within the limits of the graduations in the ordinary measuring burette.

The "universal tube" is found particularly advantageous when, for example, the amount of nitroglycerin in a sample is so small that the volume of gas generated is insufficient to fill the large reading burette to its graduated portion. The volume of gas generated from any amount of nitroglycerin up to about 0.75 gram may be read in the "universal tube." Readings in this measuring tube can be as accurately made as in the regular reading burette.

PROCEDURE.

To determine the amount of nitroglycerin in the ether extract of a dynamite, the sample from which the ether has been evaporated is dissolved in 5 to 10 c. c. of sulphuric acid (specific gravity, 1.84) and transferred to the generating bulb of the nitrometer, the beaker and the cup of the nitrometer being rinsed with several further additions of acid until 20 to 25 c. c. has been used. If the quantity of nitroglycerin present is too great, the sample dissolved in sulphuric acid is transferred to a burette and an aliquot part run into the nitrometer cup and washed into the generator with about 20 to 25 c. c. of sulphuric acid. The maximum amount of pure nitroglycerin used should be not greater than 0.75 gram in order that the gas generated will not exceed the volume of the reading burette.

The generator is then shaken gently until the generation of gas has forced out all but about 60 to 75 c. c. of the mercury, the reservoir being lowered if necessary in order to reduce the amount of mercury to this extent. The cock at the bottom of the generator is then closed and the generator shaken violently for about two to three minutes. After allowing all bubbles to separate from the reaction mixture, the gas is transferred to the reading burette, the surface of the mercury in the burette is brought to the same level as that in the compensating burette when the dry air in the compensating burette occupies the standard volume indicated by the strip of paper attached in calibrating.

The gas is allowed to stand for a few minutes to obtain an equilibrium of temperature, the levels being readjusted if necessary, and the reading is noted. This reading divided by 18.50 equals the weight of nitroglycerin in the sample used for the determination.

A more or less serious error to be considered in the determination of nitroglycerin is that introduced by losses due to volatilization of the nitroglycerin during the evaporation of the ether. To determine the effect of the rapidity of evaporation on the amount of nitroglycerin lost, weighed samples (0.6 to 0.7 gram) of nitroglycerin were placed in 100 c. c. beakers, treated with 50 c. c. of ether, the ether evaporated at different rates, and the samples dried in vacuum desiccators to remove the moisture taken up during the evaporation of the ether. Nitrogen was then determined by means of the nitrometer, the weight of nitroglycerin being calculated from the nitrometer reading. The results obtained are tabulated below:

Loss of nitroglycerin on evaporating ether extract.

[Determinations by J. H. Hunter.]

1	2	3	4	5	6	7
Sample.	Original weight of sample.	Weight of residue after evaporation of ether.	Nitrometer reading.	Weight of nitroglycerin found by nitrometer.[a]	Loss of nitroglycerin (2–5).	Method of evaporation.
	Gram.	*Gram.*	*Per cent.*	*Gram.*	*Gram.*	
1	0.6469	0.6458	11.73	0.6389	0.0080	At room temperature overnight.
2	.6328	.6318	11.53	.6280	.0048	Do.
3	.6212	.6140	11.17	.6084	.0128	Gentle boiling.
4	.6643	.6375	....	....	[b].0268	Do.
5	.6199	.6167	11.31	.6160	.0039	Do.
6	.6666	.6660	11.96	.6514	.0152	Current of compressed air blown over beaker.
7	.6773	.6710	12.10	.6590	.0183	Do.

[a] Weight of nitroglycerin = nitrometer reading + 18.50.

[b] Loss of weight.

No attempt was made to obtain constant weight after evaporation of the ether, the samples being left in vacuum desiccators only long enough to remove most of the water; hence the weights in column 3 are greater than the weights of nitroglycerin calculated from the nitrogen found (column 5).

The figures in column 6 represent the differences between the weights in columns 2 and 5.

It was noted that rapid removal of the ether, either by means of gentle heating or by means of an air current, caused a greater loss of nitroglycerin than did slow spontaneous evaporation at room temperature, the only exception being in the case of sample 5, with which the loss of nitroglycerin was only 0.0039 gram, the ether being volatilized by gentle boiling. The large loss noted with sample 4 was probably due to spurting.

Such losses as are shown in the table do not greatly affect the determination of nitroglycerin in a sample of dynamite. Thus, in analyzing a 6-gram sample of dynamite, a loss of 0.01 gram of nitroglycerin would be equivalent to only 0.17 per cent of the original sample. The importance of the error is of course greater as the percentage of nitroglycerin in the sample is less.

Evaporation in the bell-jar evaporator.—An improved method of removing the ether from the ether extract without appreciable loss of nitroglycerin was devised by A. L. Hyde in the bureau's laboratory. The beaker containing the ether solution is placed on a ground-glass plate and covered by a glass bell jar about 6 inches in diameter and 8 inches high, having two tubulures, one at the top and one on the side, each opening being fitted with a perforated stopper and delivery tube. A rapid current of compressed air, dried by passage through concentrated sulphuric acid, in two wash cylinders, is allowed to enter through the glass tube in the top of the bell jar, the lower end of the tube being about one-half inch above the surface of the ether solution in the beaker. The air current is so regulated that a marked "dimple" is made in the surface of the solution, care being taken to prevent any loss by spattering. The possibility of acid being mechanically carried over from the cylinders is avoided by connecting an empty trap between the cylinders and the bell jar. The ether vapors pass out through the glass tube in the side tubulure and may be conducted out of the laboratory through a rubber tube passing to a hood or out of a window.

The low temperature produced by the rapid evaporation of the ether minimizes the volatilization of the nitroglycerin, and the fact that the air is thoroughly dried prevents any deposition of moisture in the beaker, so that it is not necessary to desiccate the residue after the ether has entirely volatilized.

The following preliminary tests show the efficiency of the method: A weighed quantity of nitroglycerin was dissolved in 50 c. c. of ether, the ether evaporated as described, and the residue in the beaker weighed at intervals.

Loss of nitroglycerin by evaporation of ether solution in bell-jar evaporator.

Time of evaporation.	Weight of sample.			
	A	B	C	D
Hours.	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0	[a] 2.838	[a] 3.236	[a] 2.979	[a] 2.620
2	3.176	3.359	3.189	2.801
3	2.941	3.286	....	....
4	2.881	3.262	3.037	2.644
5	2.863	3.251	....	....
6	2.856	3.245	2.987	2.623
7	2.851	3.241	2.984	2.621
9	2.843	3.236	2.978	2.619
11	2.841	3.235	2.977	2.618
14	2.837	3.234	....	....

[a] Original weight of nitroglycerin.

U. S. P. ether (96 per cent) was used in tests A and B, and alcohol-free ether (distilled over sodium) in tests C and D. When the 96 per cent ether was used a distinct odor of acetic aldehyde was noticed and the rate of loss of weight was slightly lower, due no doubt to the presence of alcohol in the ether.

It is apparent from the above results that this method offers a convenient and rapid method of removing the ether without appreciable loss of nitroglycerin. Evaporation for about six hours removes the ether sufficiently to permit determination of the nitroglycerin in the nitrometer.

DETERMINATIONS OF SULPHUR, RESINS, ETC.

The sulphur used in dynamite is the form known as crushed brimstone. It is soluble in about 100 parts of ether at 23.5° C.,[a] and unless present in large amount in the sample of explosive being analyzed it will all be removed by the extraction with ether. However, when a considerable amount of sulphur crystallizes out in the ether extract, it is always advisable, after the water extraction, to make a further extraction of the explosive with carbon disulphide, in order to insure the complete removal of the sulphur.

As already mentioned, the analysis of an explosive is carried out in duplicate, one sample of the ether extract being used for the determination of nitroglycerin, the duplicate sample being used for the determination of sulphur, resins, etc. The duplicate sample is treated as follows: The weighed extract is redissolved in a mixture of ether and alcohol previously neutralized with standard alkali. The solution thus obtained is titrated with standard alcoholic potash to determine resins, phenolphthalein being used as an indicator. Determinations of a number of samples of commercial rosin (colophony) gave rather uniform results, 1 c. c. of normal alkali being found equal to 0.34 gram of rosin, which agrees with the value given by Lewkowitsch.[a]

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 85.

After titration a large excess of alcoholic potash is added and the mixture is heated on the steam bath, preferably overnight, in order to saponify the nitroglycerin. It must be remembered that nitroglycerin so treated saponifies slowly. Hence the reaction must not be hastened by heating to a higher degree than that obtained on a water bath, as an explosion may result. When saponification is complete the residue left upon evaporation is shaken with water and ether and separated in a separatory funnel. Any oily material (vaseline, paraffins, etc.) that can not be saponified is dissolved in the ether and may be weighed after evaporation. The water solution is acidified with hydrochloric acid and treated with bromine to oxidize the sulphur. Any rosin that was originally present will have formed a soap with the alkali; the acid decomposes this soap, and the rosin separates out from the acid liquid, floats on it, and may be readily removed, dried, and weighed, the weight serving as a check on the results of titration. The sulphur is oxidized to sulphuric acid by the bromine and may be determined by precipitation as barium sulphate.

Sulphur may be separated from nitroglycerin by a method depending on the fact that nitroglycerin is soluble in 70 per cent acetic acid, whereas sulphur dissolves only slightly in either glacial or 70 per cent acetic acid. The extent to which sulphur dissolves in acetic acid was determined by experiments with both brimstone and flowers of sulphur, in both cases the material being pulverized so as to pass through an 80-mesh sieve.

One gram of sulphur was digested in 100 c.c. of acetic acid for a definite period of time; the mixture was then washed on to a weighed Gooch crucible, dried for five hours at 70°, and weighed. The loss in weight represented the amount of sulphur dissolved by 100 c. c. of acid. The results were as follows:

Solubility of sulphur in acetic acid.

[Determinations by J. H. Hunter.]

Form of sulphur.	100 c. c. of 70 per cent acetic acid.			100 c. c. of glacial acetic acid.		
	Temperature.	Time.	Weight of sulphur dissolved.	Temperature.	Time.	Weight of sulphur dissolved.
	° C.	*Hours.*	*Gram.*	*° C.*	*Hours.*	*Gram.*
Brimstone	25	1	0.000	25	1	0.0338
	25	25	.000	25	1	.0354
	80	1	.0226	80	1	.1658
	80	1	.0127	80	1	.1464
Flowers of sulphur	25	20	.0115	....	....	....
	25	20	.0090	....	....	....
	80	1	.0027	....	....	....
	80	1	.0036	....	....	....

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[a] Lewkowitsch, J., Chemical technology and analysis of oils, fats, and waxes, vol. 1, 1909, p. 502.

These determinations show that sulphur (brimstone) can be separated from nitroglycerin by means of acetic acid (70 per cent) at ordinary room temperature without appreciable loss of the sulphur.

EXTRACTION WITH WATER.

The determination of water-soluble constituents is made on the dried and weighed residues left in the crucibles after extraction with ether. The apparatus used consists of an ordinary heavy-walled side-neck suction flask provided with a rubber stopper, through which passes a carbon filter tube. The crucible is inserted in the top of the filter tube, a tight joint being obtained by means of a short length of thin-walled rubber tubing. As the analysis is made in duplicate, two suction flasks so arranged are connected to a Y tube, and both samples are extracted at once. A Bunsen valve or an empty bottle to serve as a trap should be inserted between the Y tube and the suction pump to guard against any tendency of the water to "suck back."

Cold water is used for the extraction because hot water would partly gelatinize any starch that might be present, and hot water would also remove more soluble organic material from the wood pulp. The water is passed through each sample in small quantities (about 20 c. c.) at a time. The sample is covered with water, allowed to stand a short time, and suction applied until all the water has passed into the flask. This process is repeated until at least 200 c. c. of water has been used. If each portion of water is allowed to stand on the sample for a short time and then thoroughly sucked out, this quantity of water is more than sufficient for complete extraction, but in case of doubt a few drops of the last portions of the filtrate is tested by evaporation on a glass plate.

If starch is present the filtration often proceeds very slowly because of the tendency of the starch to separate at the bottom of the crucible and form an almost impermeable layer on top of the asbestos mat. In such cases the use of stronger suction simply increases the density of this mass and retards rather than aids filtration. When any considerable quantity of starch has been detected in the qualitative examination, it is advisable to make use of porous alundum crucibles for the analysis, since these allow the filtrate to pass through the walls above the dense material at the bottom. With these crucibles it is necessary to use carbon tubes of such diameter that the crucible projects the greater part of its depth into the tube, being held by the rubber about one-fourth inch from its top. If this is not done there is a tendency for the filtrate to leak out of the crucible above the rubber.

These porous crucibles have been found decidedly convenient, especially in the case of materials that tend to clog the ordinary Gooch crucible.

The water extraction having been completed, the crucibles, with their contents, are again placed in the drying oven and dried for five hours at about 95 to 100° C. No additional loss results from longer drying at this temperature, and frequently to save time samples are dried overnight. After cooling in a desiccator the crucibles are weighed and the loss of weight noted. This loss of weight represents the total water-soluble material, and, in addition to the water-soluble salts detected in the qualitative examination, includes organic extract from the wood pulp, flour, or other absorbent. When cereal products are present the amount of organic material thus extracted may amount to 2 per cent or more, including sugars, etc., that form constituent parts of the grain. Frequently the antacid used, generally calcium carbonate or magnesium carbonate, is attacked by acid decomposition products from the nitroglycerin, a portion of the carbonate being thereby converted to nitrate or nitrite. In such cases some calcium or magnesium is found in the water extract.

Usually the only water-soluble constituent to be considered in an ordinary dynamite is an alkaline (sodium or potassium) nitrate. When an approximate analysis only is desired it is generally considered sufficient to regard the total loss of weight on extraction as nitrate, but, as shown above, this frequently gives erroneous results.

DETERMINATION OF ALKALINE NITRATES.

The method best suited for determination of nitrates is the following: An aliquot portion of the water extract is evaporated to dryness on a water bath and the residue gently ignited to burn off the organic matter. After cooling, the sides of the evaporating dish are washed down with a few cubic centimeters of water, about 1 c. c. of nitric acid is added, the evaporation repeated, and the residue heated gently over a burner until just fused, or the residue is dried in an oven at about 120° C. The treatment with nitric acid is necessary for the complete conversion to nitrate of any nitrite resulting from burning off the organic matter. The treatment should be repeated until the weight of the residue is constant.

The weighed residue is calculated as percentage of nitrate in the original explosive. Since this weight necessarily includes any nonvolatile water-soluble impurities originally present in the nitrate, as iron, aluminum, chlorides, sulphates, etc., for an exact analysis it is necessary to ascertain the amount of such impurities by volumetric or gravimetric determinations on fresh aliquot portions of the water extract, or a direct determination of the true nitrate content may be made in the nitrometer as described on the following page.

DETERMINATION OF ALKALINE NITRATES BY MEANS OF THE NITROMETER.

An aliquot portion of the water extract estimated to contain the proper amount of nitrate for determination in the nitrometer (about 0.6 to 0.8 gram of $NaNO_3$ or 0.8 to 1.0 gram of KNO_3 for the type of nitrometer previously described, p. 35) is evaporated almost to dryness on a steam bath and transferred, by means of as little water as possible, to the cup of the nitrometer. The amount of water used should not exceed 20 c. c. This solution is drawn into the generator, and 30 to 40 c. c. of sulphuric acid (95 to 96 per cent) is added slowly, in small quantities at first to avoid generating sufficient heat to crack the glass. Because of the dilution of the acid the generation of the gas proceeds much more slowly than in the determination of nitroglycerin, and it is necessary to shake the generator for a total time of about 8 to 10 minutes in order to be certain that the reaction is complete. The volume of gas is measured and the percentage of nitrate is calculated in the same manner as in the case of nitroglycerin. This method is excellent for use as a check or for an exact determination of the actual nitrate content.

Tests made on a 1 per cent solution of pure potassium nitrate by both the gravimetric and volumetric methods described above gave results as follows:

Results of determinations of nitrates in a water solution by the gravimetric and by the volumetric method.

[Determinations by J. H. Hunter.]

Test No.	Volume of solution used.	Weight of KNO_3 used.	Gravimetric method.	Volumetric method.	
			Weight of KNO_3 found.	Reading of nitrometer (N).	Weight of KNO_3 found.
	c. c.	Grams.	Grams.		Grams.
1	100	1.0000	0.9994	....	....
2	100	1.0000	....	13.92	1.0036
3	100	[a]1.0000	.9997	....	....
4	100	[a]1.0000	....	13.92	1.0036
5	100	[b]1.0000	1.0004	....	....
6	100	[b]1.0000	....	13.93	1.0043

[a] Two one-hundredths gram of sugar was added to the 100 c. c. of nitrate solution.

[b] Two one-hundredths gram of sodium chloride was added to the 100 c. c. of nitrate solution.

EXTRACTION WITH ACID.

As already pointed out, the materials most commonly used as antacids are the carbonates of calcium or magnesium or the oxide of zinc. Frequently ground dolomite is used, in which case both calcium and magnesium must be determined. The qualitative examination will have shown, however, what acid-soluble materials are present.

The procedure to be followed in making the acid extraction depends on whether or not starch is present in the explosive. In either case the dried and weighed residue insoluble in water is used for the treatment with acid.

In the absence of starch a simple extraction is made with cold dilute hydrochloric acid (1:10), 100 c. c. being drawn through the sample in the crucible in small successive portions, as described under "Extraction with water" (p. 43). Several portions of water are then drawn through to wash out the acid, and the crucible with the insoluble residue is dried as before for five hours at 95 to 100° C. It is sufficiently accurate to use this "loss-of-weight" figure as the amount of antacid, as the amount of organic material extracted from the wood pulp will be very small, but if greater accuracy is desired a quantitative determination of the dissolved base or bases may be made by the usual gravimetric methods

DETERMINATION OF CALCIUM.

Calcium is determined as follows: An excess of ammonium hydroxide is added and the solution boiled. Any precipitate of iron or aluminum hydroxides may be filtered off, ignited, and weighed, but the amount of such impurities is usually so small that it may be disregarded and calcium precipitated without previous filtration. Hot ammonium-oxalate solution is added in slight excess to the boiling solution and the boiling is continued for a short time. The precipitate is allowed to settle completely, and then is filtered, dried, and weighed as CaC_2O_4, or is ignited and weighed as CaO.

DETERMINATION OF MAGNESIUM.

Magnesium is determined in the filtrate from the calcium determination by concentrating to about 100 c. c., adding an excess of a solution of sodium hydrogen phosphate to the hot solution, then a large excess of ammonium hydroxide, and allowing the phosphate precipitate to separate completely by standing for several hours. The precipitate is filtered in a Gooch crucible, washed, ignited, and weighed as $Mg_2P_2O_7$.

DETERMINATION OF ZINC.

Zinc is precipitated with Na_2CO_3 solution as carbonate, ignited, and weighed as ZnO. If ammonium salts are present the zinc is precipitated with H_2S as ZnS, the ZnS filtered off, redissolved, and precipitated as carbonate. The determination of zinc is more fully considered in the discussion of ammonia dynamites on page 58.

DETERMINATION OF STARCH.

When starch is present both the starch and the antacid are removed in one operation by boiling with dilute acid, whereby the starch is rendered soluble by conversion to dextrin. In carrying out this process the material in the crucible is moistened with water and completely transferred with a spatula, or by washing with a stream of water from a wash bottle, into a beaker of about 500 c. c. capacity. If a Gooch crucible is used the asbestos is removed with the residue and the clean crucible dried and weighed. From the original weight of the crucible plus the asbestos the weight of the asbestos is ascertained and deducted from the final weight of dried residue remaining after hydrolysis. The volume of water in the beaker is made up to about 250 c. c., and about 3 c. c. hydrochloric acid (specific gravity 1.2) is added, and the mixture is stirred and brought to boiling over a burner. Boiling is continued until the starch is entirely hydrolized, a drop of the acid mixture being tested from time to time on a spot plate with a solution of iodine in potassium iodide until a blue coloration is no longer obtained. Longer boiling will only result in loss of extractive material from the wood pulp.

The boiled material is then at once filtered through a fresh crucible or through the original porous crucible, if such was used, washed several times with water, dried as before, and weighed. If the figures representing the weight include the weight of the asbestos mat from a Gooch crucible, the proper correction for the weight of the asbestos is made as noted above.

The amount of antacid contained in the acid filtrate is ascertained by a gravimetric determination as previously described.

It has already been noted (p. 44) that small amounts of soluble organic material (sugars, dextrin, etc.) from flour or other cereal products and extract from the wood pulp will be found in the water solution. In summarizing the results of analysis it is of course impossible to know what portion of such extracted organic material constituted part of the flour and what portion should properly be added to the wood pulp. Similarly, the organic material dissolved during the acid hydrolysis includes not only such portions of the grain as starch and gluten but soluble portions of the wood pulp.

It is customary in quoting the results of analysis to include all such soluble organic material from both water and acid extractions under the term "starch," and the insoluble residue is designated as "wood pulp and crude fiber.'' In other words, the weight of insoluble residue dried at 100° is called "wood pulp and crude fiber,'' whereas the sum of this constituent and of the ingredients determined in the ether, water, and acid solutions, deducted from the weight of original sample, is called "starch.''

In the case of a dynamite which contains no cereal product, the sum of the determined ingredients deducted from the weight of original sample is taken as the amount of wood pulp present and includes the material extracted from the pulp by the water and acid treatment as well as the insoluble residue found by direct weight.

The actual amounts of wood pulp and of cereal products added in manufacture can not therefore be definitely determined, since portions of each will be found in the ether, the water, and the acid extractions as well as in the insoluble residue.

In order to determine to what extent the wood pulp in a dynamite is affected by the various extractions, etc., necessary in the course of analysis of the dynamite, dried samples of various grades of pulp were submitted to the treatment through which the insoluble wood pulp residue in a sample of dynamite had passed.

Samples of 2 to 3 grams of wood pulp were weighed in Gooch crucibles, dried to constant weight, and extracted successively with ether, water, and cold hydrochloric acid (1:10), and then boiled for 15 minutes with dilute hydrochloric acid (1:100). The latter treatment would be necessary if starch were present with the wood pulp in an explosive. After each operation the sample was dried five hours at 100°, and the loss of weight was determined. The results were as follows:

Results of analyses of wood pulp.

Sample No.	Loss of weight (per cent of dry sample.)				Percentage of insoluble residue.
	Extraction with ether.	Extraction with cold water.	Extraction with cold HCl(1:10).	Boiling with HCl (1:100)	
1........	2.66	2.57	1.41	5.91	87.45
2........	2.78	2.89	.42	1.75	92.16
3........	2.09	2.23	.53	3.93	91.22
4........	1.95	2.84	1.03	4.83	89.35

These experiments show that the final insoluble residue that is weighed as wood pulp may be only about 90 per cent of the amount of dry wood pulp actually present in the dynamite. A part of the loss is determined as rosin in the ether extract, and the portions extracted with water and hot acid are calculated as starch (if starch has been determined). When starch is not present the error in the determination of pulp is much less as the boiling-acid treatment is dispensed with. The analysis can then be made accurate by direct determination of the water-soluble nitrate and of the antacid as described above, and the amount of wood pulp can be found by subtracting the sum of the percentages of moisture, nitroglycerin, alkaline nitrate, and antacid from 100 per cent. This amount will be in excess of the percentage of insoluble residue found, according to the amounts of pulp extracted by the water and acid.

EXAMINATION OF INSOLUBLE RESIDUE.

DETERMINATION OF WOOD PULP, ETC.

The residue that remains after the ether extraction, the water extraction, and the extraction with dilute acid is usually a mixture of wood pulp, sawdust, or other form of cellulose or lignin. When corn meal, flour, middlings, bran, etc., are present in the dynamite, the residue will contain the nonstarchy portions of these materials, either free or mixed with wood pulp. In general, ordinary dynamite contains wood pulp alone as the absorbent, but low-freezing dynamites and "straight" dynamites containing less than 40 per cent of nitroglycerin often contain considerable quantities of corn meal, wheat middlings, or low-grade flour.

Infusorial earth was formerly much used as an absorbent for nitroglycerin, but in recent years it has seldom been so used in this country, having been almost entirely replaced by an active base or dope.

If the hydrochloric acid has not been thoroughly washed from the insoluble residue, the wood pulp will considerably darken in color during the drying process. From its physical structure, as observed without magnification, or with a small lens, much information may be gained in regard to the probable composition of the insoluble residue, but in all cases the examination is best made under the microscope, with a low-power objective, one of 32-mm. focus being suitable. One of the duplicate samples of insoluble residue is used for microscopic and chemical examination, and one for the determination of ash. A small amount of the sample which is to be used for microscopic and chemical examination is removed from the crucible, placed upon a microscope slide, and moistened with one or two drops of water. By means of a platinum needle the material is then carefully spread out, but no cover glass is used. Wood pulp, the most common constituent in the residue of ordinary dynamite, will be seen as separate fibers or bunches of fibers of very characteristic appearance.

In Plate IV, *A* and *B*, wood pulp of different grades is illustrated, and the characteristic appearance of sawdust or dust from certain types of woodworking machinery is shown in Plate IV, *C*. The bundles or clusters of fibers are characteristic of such materials. Typical samples of infusorial earth (kieselguhr) are shown in Plate IV, *D* and *E*. It should be noted that, as plainly shown in the figures, widely differing types of infusorial earth exist, forms of organisms appearing in one sample which will not be found in another. The general appearance of shell remains is a definite indication of the presence of diatomaceous or infusorial earth. The sample shown in Plate IV, *D*, was obtained, through the courtesy of Dr. G. P.

Merrill, from the National Museum, Washington, D. C. (Specimen No. 6555, from Cornwallis, Nova Scotia.)

The appearance of the "husks" or crude fiber from coarse wheat flour (middlings), after hydrolysis of the starch, is shown in Plate IV, *F;* the cellular structure of the irregularly shaped particles of fiber is readily seen.

A and *B*, Plate V, represent cellulose (cotton) and nitrocellulose, respectively. These two materials can not be distinguished from each other by microscopic examination in ordinary light, but in polarized light a decided difference is noted, the unnitrated fibers appearing in brilliant colors and the nitrated fibers dark.

In the case of the presence of cereal products it is often of value to make a microscopic examination of the residue insoluble in water before hydrolysis of the starch. In Plate V, *C*, *D*, and *E*, such materials are shown. *C* represents ordinary fine wheat flour; *D*, wheat flour mixed with wood pulp; *E*, coarse wheat flour or middlings; and *F*, corn meal. Characteristic differences in the appearance of the starch granules of wheat and corn are of aid in identifying these cereals, the wheat starch granules being in general well rounded or oval, whereas the cornstarch granules are almost always distinctly polygonal in shape.

DETERMINATION OF ASH.

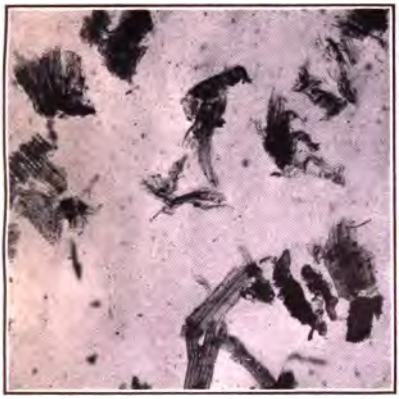
The remaining sample of residue from acid extraction is used for the determination of ash, and may be either incinerated in the crucible that has been used for extraction, or the residue, together with the asbestos mat, may be removed to a platinum crucible and ignited; in this case there is subtracted from the ash the known weight of asbestos present in the mat. The ash of an ordinary dynamite, containing only wood pulp, sawdust, or corn meal as absorbents, will seldom amount to more than 0.20 per cent. When the amount of ash present is as much as 0.5 per cent the ash should in all cases be examined under the microscope to determine the possible presence of infusorial earth or other inorganic material (pulverized glass, sand, etc.), provided the presence of these materials has not already been detected by the microscopic examination. A high ash content may also indicate that either the water or acid extractions have not been complete. In this respect the ash determination may be regarded as a check on the analysis.

VARIATIONS DUE TO METHOD OF ANALYSIS.

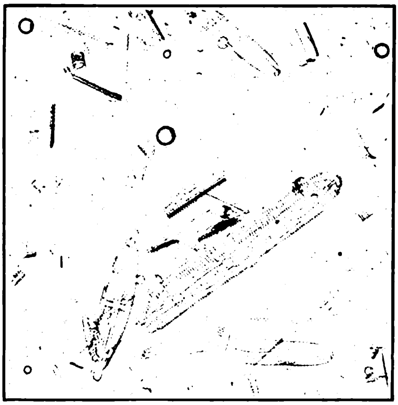
In order to ascertain to what extent the results of analysis of a dynamite would be effected by variations in the method of analysis, uniform samples of a 45 per cent dynamite were submitted to the laboratories of 11 explosives works, with the request that analyses be

A. WOOD PULP NO. 1 (X 50).

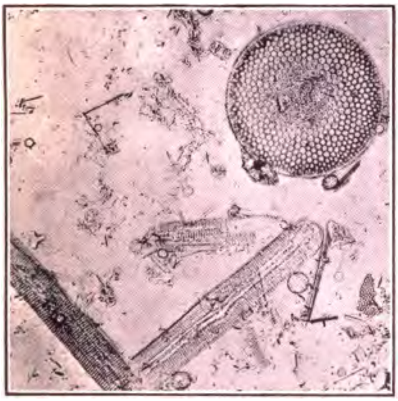
B. WOOD PULP NO. 2 (X 50).



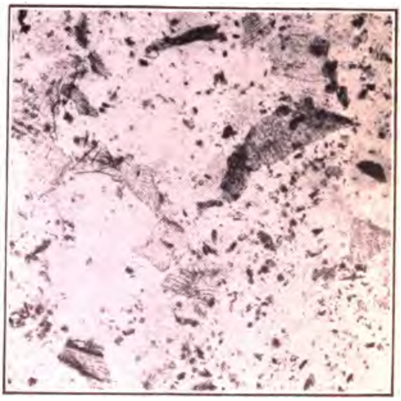
C. SAWDUST (X 25).



D. INFUSORIAL EARTH NO. 1 (X 150).



E. INFUSORIAL EARTH NO. 2 (X 150).



F. CRUDE FIBER FROM WHEAT MIDDLINGS (X 25)

made by the methods regularly in use in each laboratory and results reported, together with brief notes as to the method used.

The samples were prepared as follows: Fifty cartridges of a lot of 45 per cent dynamite were opened, about two-thirds of each cartridge removed (the ends being rejected), and broken up finely in a porcelain dish by means of a horn spoon. All of these portions were then mixed together very thoroughly in a large porcelain dish. From this uniform mixture about 20 sample bottles (150 c. c. capacity) were filled, the contents of each bottle then being emptied out separately into a dish, carefully mixed again, and replaced in the bottle. Each sample represented about 150 grams.

Eleven of these samples were sent to different laboratories, as noted above, and seven of them analyzed in the bureau's explosives chemical laboratory by different analysts. Careful instructions were sent with each sample, that, in order to compensate for any segregation occurring in shipment, the entire sample should be thoroughly mixed before analysis.

The results of the analyses of these samples are shown in the following table:

Analyses of uniform samples of dynamite.

1	2	3	4	5	6	7	
Sample No.	Moisture.	Nitroglycerin.	Potassium nitrate.	Calcium carbonate.	Wood pulp.	Nitroglycerin.	
						By direct weighing.	By nitrometer.
A	1.21	43.90	39.14	1.02	14.73	....	....
B	.89	44.99	38.40	1.15	14.57	....	....
C	.99	44.77	38.75	1.06	14.59	....	....
D	.91	45.25	38.62	.98	14.24	....	....
E	1.05	44.52	38.05	1.28	15.10	....	....
F[a]	1.02	42.29	41.02	1.15	14.52	....	....
G	.41	44.91	39.04	1.12	14.52	....	....
H	1.35	44.86	38.09	1.28	14.42	....	....
J	1.22	44.98	38.48	.99	14.37	....	....
K[b]	....	....	....	....	....	....	....
L	1.60	44.50	37.40	1.00	15.50	....	....
M	1.00	45.70	37.57	1.17	14.56	....	....
N	1.19	45.50	37.54	1.15	14.62	....	....
O	1.15	45.48	37.69	1.16	14.52	45.87	45.22
P1	1.04	45.35	37.66	1.10	14.85	45.31	45.17
P2	1.26	45.22	37.33	1.20	14.88	....	....
P3	.98	45.24	37.87	1.21	14.70	....	....
Q	1.18	45.42	37.60	1.19	14.61	45.41	45.14

[a] The remarkable difference noted in the analysis of this sample as compared with all other samples, is due to the fact that, through misunderstanding, this sample was not mixed on being received. After several analyses had been made with widely varying results, the remainder of the sample was mixed by rubbing through sieves. This treatment probably resulted in considerable loss of nitroglycerin. Sample F is therefore not considered in the discussion of results.

[b] No report received.

Samples A to L were analyzed in the laboratories of various powder companies and samples M to Q in the bureau's laboratory; P2 and P3 were analyzed by men under instruction, not members of the laboratory force of the bureau.

DISCUSSION OF ANALYSES.

MOISTURE.

The methods employed were as follows:

Samples E, J, and M to Q, inclusive—3 grams desiccated on watch glass over H_2SO_4 for 3 days (0.98–1.26 per cent).

Sample A—6 to 10 grams on watch glass, 3 days over H_2SO_4 (1.21 per cent).

Sample B—3 grams on watch glass, 2 days over $CaCl_2$ (0.89 per cent).

Sample D—6 grams on watch glass, 24 hours over H_2SO_4 in vacuum (0.91 per cent).

Sample C—2 grams on watch glass, 24 hours over H_2SO_4, 15 inches vacuum (0.99 per cent).

Sample H—5 grams in Gooch crucible, 48 hours over H_2SO_4 at 40° C. (1.35 per cent).

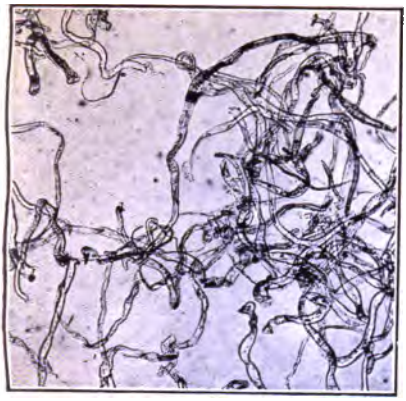
Sample G—10 grams in 4-ounce bottle, dry-air current passing *over surface* of sample for 24 hours (0.41 per cent).

Sample L—10 grams in drying tube, dry-air current passing *through* sample for 24 hours (1.60 per cent).

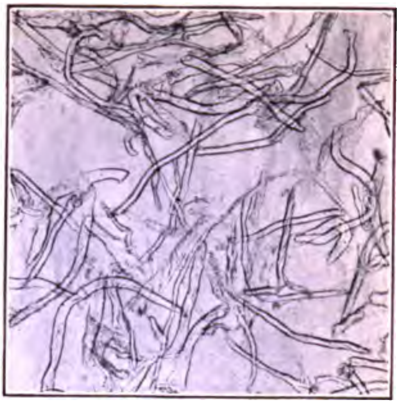
It is noted that desiccation on a watch glass over H_2SO_4 for three days gave only 0.3 per cent maximum variation, results obtained with the aid of vacuum for 24 hours being a little low. Two days over $CaCl_2$ gave low results. High results were obtained by desiccating at 40° C. and by passing dry air through the sample, from loss of nitroglycerin under these conditions. Passing dry air over the surface of the sample gave low results, as might be expected.

NITROGLYCERIN.

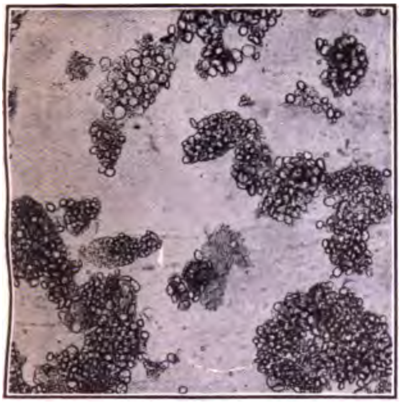
The results obtained in the bureau's laboratory with samples M to Q varied from 45.22 to 45.70 per cent. Samples of 5 to 10 grams in Gooch crucibles were extracted for one hour with U. S. P. ether (96 per cent) in the Wiley apparatus and the residues dried five hours at 100° C. The loss in weight minus the moisture previously determined was taken as the nitroglycerin content. Samples B, E, and J were analyzed in the same manner, giving results from 44.52 to 44.99 per cent. Samples A, C, D, G, and L were extracted with ether by means of suction, 7 to 10 grams of sample being treated with five or six successive portions of ether (amounts varying from 50 to 120 c. c.). Samples A, C, and D were dried to constant weight in steam ovens after extracting (the time of drying not noted); G was dried at 100° to 105°, and L for two hours at 95°. The results varied from 43.90 to 45.25 per cent. The results obtained in the bureau's laboratory (45.22 and 45.70 per cent) are uniformly higher than those obtained in other laboratories (43.90 to 45.25 per cent).



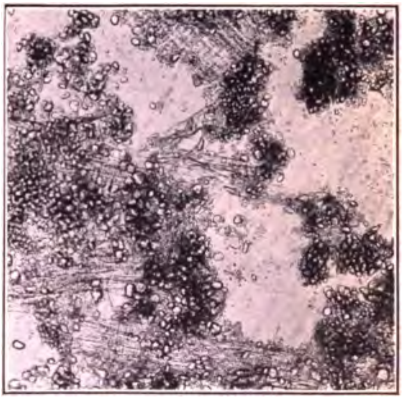
A. CELLULOSE (COTTON) (X 50).



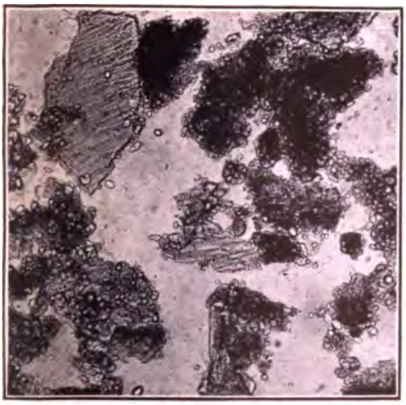
B. NITROCELLULOSE (X 50).



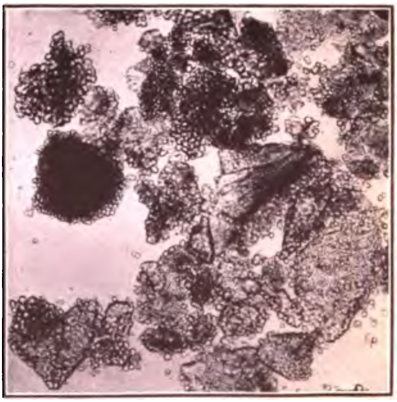
C. WHEAT FLOUR (FINE) (X 50)



D. WHEAT FLOUR (FINE) AND WOOD PULP (X 50).



E. WHEAT FLOUR (MIDDLINGS) (X 50).



F. CORN MEAL (X 50).

Nitrometer determinations on three samples (column 7) showed the true nitroglycerin content of the evaporated ether extracts to be approximately 45.2 per cent.

No explanation can be given for the large number of results in which the amounts of nitroglycerin found are uniformly low, except failure to observe one or more of the following precautions: (1) The extraction must be complete; (2) the residue must be dried to constant weight at a temperature of about 100° C.; (3) the dried residue must be cooled in an efficient desiccator and weighed as soon as cooled.

POTASSIUM NITRATE.

The results obtained in the bureau's laboratory varied from 37.33 to 37.87 per cent. The determination was made by extracting the residue insoluble in ether with about 200 c. c. of water, and determining the nitrate in an aliquot part of the water solution by evaporation, as described on page 44. No correction was made for traces of chlorides, etc., in the solution. The determination on sample H was made in the same manner, giving 38.09 per cent, while on sample L an aliquot portion of the water extract was analyzed in the nitrometer with a result of 37.40 per cent. All the remaining samples were extracted with water, the insoluble residues dried at about 100C°. and weighed, the loss of weight being regarded as potassium nitrate. This method gave high results (38.05 to 39.14 per cent) owing to the water-soluble organic matter extracted from the wood pulp.

CALCIUM CARBONATE.

In samples L to Q the calcium carbonate was determined gravimetrically in the dilute-acid extract; in samples C and D by direct titration of the residue insoluble in water, or of the ash left after burning off the pulp; in A, B, E, and J the loss of weight on extraction with dilute acid was considered as calcium carbonate, while in G and H the ash was assumed to be entirely calcium carbonate. The variations are of minor importance and no conclusions can be drawn from the results.

WOOD PULP.

Variations in the method of determining the potassium nitrate influence the proportion of wood pulp reported. When the loss of weight on extracting with water is assumed to be entirely potassium nitrate, in spite of the fact that it contains considerable organic matter extracted with the wood pulp, the proportion of wood pulp found will be lower than if the nitrate is determined by a direct method and the wood pulp by difference. The percentage of wood pulp being found by subtracting the sum of all other constituents from 100 per cent, no comparison of results is possible.

GELATIN DYNAMITE.

Unlike ordinary dynamite, which contains nitroglycerin absorbed in a porous material, gelatin dynamite contains nitroglycerin combined with nitrocellulose to form a plastic solid. When nitroglycerin is warmed with nitrocellulose containing about 12 per cent of nitrogen, the nitroglycerin dissolves the nitrocellulose, and a thick, viscous mass is produced which resumes a jelly-like consistency as soon as it has cooled. When as little as 3½ per cent of nitrocotton is dissolved in nitroglycerin at 60°, the material should form a jelly-like nonflowing mass when cooled to ordinary temperatures, but when smaller amounts of nitrocellulose are used the viscosity of the solution becomes less. The explosive known as "blasting gelatin" consists of about 93 to 90 per cent of nitroglycerin and 7 to 10 per cent of nitrocellulose, and is a translucent, jelly-like mass, containing the highest percentage of nitroglycerin used in any solid explosive.

Any explosive containing nitroglycerin combined with nitrocellulose in connection with an active base consisting of a nitrate and combustible material is termed a "gelatin dynamite." The gelatin dynamites have many properties that make them desirable for mining work, their greatest advantage being that they are almost unaffected by water.

SAMPLING.

The coherent, pasty, doughlike consistency of gelatin dynamite renders the preparation of a uniform sample much more difficult than is the case with ordinary dynamite.

A sample is prepared from one or more cartridges by cutting off portions from different parts of each stick; these portions are then cut into thin pieces and broken up as finely as possible by means of an aluminum or platinum spatula. The use of a steel spatula or knife is not to be recommended. The sample so prepared is well mixed and bottled, and because of its tendency to form a solid mass again on standing, it should be analyzed as soon as possible after being prepared.

The ingredients that may be found in the various types of gelatin dynamite are nitroglycerin; nitrocellulose; sulphur; rosin; sodium, potassium, or ammonium nitrate; calcium or magnesium carbonate; wood pulp; and cereal products.

Moisture is determined in the manner previously described.

The extraction with ether is made as for dynamite except that ether distilled over sodium (that is, ether free from alcohol) is used in order to avoid the partial solution of the nitrocellulose. Nitrocellulose is insoluble in pure ether, but a small percentage of alcohol present as an impurity may cause the solution of a considerable proportion of this constituent, and as the amount of nitrocellulose is usually only 0.5 to 2 per cent its determination should be accurate.

The ether solution containing the nitroglycerin, sulphur, and rosin is treated in the manner already described, and the water extraction of the dried and weighed insoluble residue is made in the usual way.

SULPHUR.

If the percentage of sulphur is unusually high, or if the extraction with ether has not been continued long enough, some sulphur may remain in the dried residue left after water extraction, in which case an additional extraction is made with carbon disulphide in the Wiley apparatus, the same method as described for the ether extraction being used. After the extraction with carbon disulphide has been made, the crucibles should be sucked dry and the carbon disulphide allowed to evaporate in a warm place before the crucibles are placed in the oven, as the vapors of carbon disulphide are very inflammable and may *ignite* in the oven. The crucibles with their dried residue are weighed and the loss of weight considered as sulphur.

The extraction with water is next made as before described.

NITROCELLULOSE.

Nitrocellulose is now removed by means of a suitable solvent. The pyroxylin cotton usually employed as a gelatinizing agent is soluble in a mixture of two parts ether and one part alcohol, but as all grades of nitrocellulose are more readily soluble in acetone than in ether alcohol it is customary to use acetone as the solvent.

The extraction with acetone is made by separating the dry residue from the crucible, leaving the mat intact if possible, placing the residue in a small beaker and covering it with acetone. The mixture is allowed to stand for three to four hours, with frequent stirring to dissolve completely the nitrocellulose, and is then filtered through the original crucible, washed with acetone, dried in the usual manner, and weighed. The loss of weight represents nitrocellulose plus a small amount of extract from the wood pulp. The wood pulp extract is usually so small that it may be disregarded, but a check on the nitrocellulose determination may be made by evaporating the acetone solution to a small volume (about 20 c. c.), and diluting gradually with a large volume of hot water (about 100 c. c.), which drives off the volatile solvent, precipitating the nitrocellulose as a white flocculent mass. The precipitate is then filtered off, dried, and weighed as nitrocellulose.

The remainder of the analysis is conducted as is that described for straight dynamite.

Some of the older types of gelatin dynamites contained small amounts (1 to 2 per cent) of paraffin, but this is an unusual ingredient and is more frequently found in ammonia dynamite. (See p. 57.)

Ammonia gelatin dynamite is a type that has of recent years assumed commercial importance. It differs from ordinary gelatin dynamite in the fact that it contains ammonium nitrate in addition to the usual constituents of the former. As in the ammonia dynamites, discussed later, so here the ammonium nitrate is usually previously coated with vaseline, paraffin, or other waterproofing material, and is neutralized with zinc oxide.

In the analysis of gelatin dynamite it should be remembered that trade custom has led to an erroneous system of designating the strength of explosives of this class. Thus a gelatin dynamite containing about 30 to 33 per cent of nitroglycerin and about 1 per cent of nitrocotton is called a "40 per cent" strength gelatin dynamite. This unfortunate practice undoubtedly had its origin in the fact that, as gelatin dynamite is much denser than ordinary dynamite, and a greater quantity can therefore be placed in a hole, it was assumed to be stronger. Comparative tests indicate that, weight for weight, a so-called "40 per cent" strength gelatin dynamite containing 33 per cent nitroglycerin is much weaker than is an ordinary "straight" dynamite containing 40 per cent nitroglycerin.

AMMONIA DYNAMITE.

The usual type of ammonia dynamite is practically a "straight" dynamite in which a large part of the nitroglycerin is replaced by ammonium nitrate. Sulphur is sometimes a constituent of this type of explosive, and frequently the wood pulp is wholly or largely replaced by coarse flour or middlings. The ammonium nitrate is generally protected from hygroscopic influence by a coating of vaseline or paraffin and is neutralized with zinc oxide. These ingredients are added to the ammonium nitrate in the course of its manufacture while the crystals of the ammonium nitrate are still hot.

In the analysis of such explosives the determination of moisture and extractions with ether, water, and acid are carried out as previously described. An additional extraction with carbon disulphide is usually necessary in order to remove all of the sulphur; this is done after the water-soluble salts have been extracted.

One portion of the ether extract is used for the determination of nitroglycerin in the nitrometer and the other for the determination of the sulphur and vaseline or paraffin.

The method for the analysis of the ether extract as described on pages 41 and 42 is the scheme of separation followed when both sulphur and vaseline, or paraffin, are present with the nitroglycerin, although several other methods are applicable and give reliable results.

The nitroglycerin may be destroyed by means of caustic alkali, which also dissolves any resin present; the solution is decanted from the residue of paraffin, or vaseline, and sulphur; the resin is precipitated with hydrochloric acid, filtered, dried, and weighed. The residue of sulphur and paraffin or vaseline is treated with hot ammonium sulphide which dissolves the sulphur; this solution is cooled, decanted, and the vaseline or paraffin adhering to the beaker is washed, dried, and weighed. The weight of sulphur is found by difference.[a]

The water extract contains both ammonium and sodium nitrates, together with water-soluble organic material from the flour or other absorbent. If zinc oxide has been used as the antacid, all of this component will generally be found in the water extract, since the small amounts used are readily soluble in ammonium nitrate solutions.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, pp. 388–389.

An aliquot part of the water extract is evaporated in a platinum dish on a steam bath, the ammonium nitrate volatilized, and the organic matter burned off by careful heating over a burner. A little nitric acid is added to oxidize to nitrate any nitrite resulting from reduction, as described on page 44. In heating this residue care must be taken to avoid decomposition of the zinc nitrate, or else the heating should be strong enough to convert it entirely to zinc oxide. Either of the following methods may be used:

(1) The residue, after evaporation of the nitric acid on the steam bath, is dried at about 110° to 120°, and weighed as $NaNO_3$ and $Zn(NO_3)_2$. This residue is then dissolved in water and the zinc precipitated with sodium carbonate, filtered, ignited, and weighed as ZnO. The weight of $NaNO_3$ and $Zn(NO_3)_2$ minus (2.33 times the weight of ZnO) equals $NaNO_3$.

(2) The residue obtained as above is heated gently over a burner until the evolution of oxides of nitrogen from the decomposition of the zinc nitrate has ceased, care being taken that the temperature is not high enough to cause a loss of sodium nitrate. The residue is now weighed as $NaNO_3$ plus ZnO, then treated with water to dissolve the $NaNO_3$; the ZnO is filtered on a Gooch crucible, ignited, and weighed as ZnO, the $NaNO_3$ being found by difference from the combined weight. The filtrate containing the sodium nitrate should be tested with ammonium sulphide to assure that the zinc has been entirely converted to insoluble zinc oxide.

Zinc may be determined in a separate portion of the water extract by adding ammonia, precipitating with hydrogen sulphide, and filtering off the precipitated zinc sulphide. The precipitate is washed and, without drying, dissolved in a small amount of nitric acid, and evaporated to dryness. Any free sulphur is thus oxidized. The residue is treated with a little sulphuric acid and again evaporated to dryness over a burner at a dull-red heat until the free acid has been volatilized. Little, if any, decomposition of the zinc sulphate results from this heating. The treatment with sulphuric acid and heating should be repeated until a constant weight of $ZnSO_4$ is obtained. This method is convenient and has been found to check well with the methods described above.

Ammonium nitrate is determined directly with a separate portion of the water extract by the usual method of distilling from a solution made strongly alkaline with KOH, collecting the distillate in a known volume of standard H_2SO_4, and titrating the excess of acid with standard alkali, cochineal being used as an indicator.

In regard to the determination of ammonium nitrate, the possible effects of several influencing factors have been investigated. Stillman and Austin state that ammonium nitrate is slightly soluble in ether,[a] and several other authors have noted that correction should be made for this solubility.

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[a] Kast, H., Anleitung zur chemischen und physikalischen Untersuchungen der Spreng- und Zündstoffe, 1909, p. 980.

Ten-gram samples of pure ammonium nitrate were desiccated to constant weight over sulphuric acid and were extracted with U. S. P. (96 per cent) ether for one hour in the Wiley apparatus. On drying to constant weight in vacuum desiccators a maximum loss of only 0.10 per cent was noted. Additional drying of the same samples at 70° for 18 hours caused a further loss of 0.07 to 0.15 per cent. On continuing the drying at 90° to 100° further losses calculated as percentages of the original sample were as follows:

Loss in weight of ammonium nitrate dried at 90° to 100°.

Time of drying.	Total loss, per cent.	
	Sample 1.	Sample 2.
Hours.		
2	0.03	0.04
5	.03	.05
24	.07	.11
120	.33	.39
240	.62	.67

The above-mentioned experiments show that the loss of pure ammonium nitrate by the ether extraction and by subsequent drying for several hours at 70° or 100° is very slight—not over 0.25 per cent.

That the loss on drying depends on the surface exposed was shown by drying, at 90° to 100°, 5-gram samples spread on 3-inch watch glasses. The losses were as follows:

Loss in weight of ammonium nitrate dried on 3-inch watch glasses at 90° to 100° C.

Time of drying.	Loss of weight, per cent.	
	Sample 1.	Sample 2.
Hours.		
5	0.34	0.33
24	.88	.98
48	2.03	1.57
120	6.11	4.64
168	7.09	5.84

In this case the much greater surface of samples exposed caused a much more rapid volatilization.

In the analysis of an explosive containing zinc oxide, it must be remembered that in addition to mere volatilization there is possible still further loss from the decomposing action of the ZnO on the ammonium nitrate. This is shown by the following experiment: Two 10-gram samples of ammonium nitrate were ground in a mortar, 0.5 gram zinc oxide being well mixed with one sample. The two samples were then placed in crucibles and heated at 100°. The losses in weight are given in the table following:

Loss in weight of ammonium nitrate with and without zinc oxide on heating at 100°.

Time.	Loss in weight, per cent.	
	Ammonium nitrate.	Ammonium nitrate plus 5 per cent of zinc oxide.
Hours.		
2	0.02	0.61
18	.11	1.07
48	.16	1.13

The effect of too high temperature of drying is shown more clearly in the following experiments with an ammonium nitrate explosive of the "permissible" class, containing nitroglycerin. The explosive contained about 75 per cent of NH_4NO_3 and 1.4 per cent of ZnO. Six 10-gram samples were extracted with ether in the usual manner to remove the nitroglycerin. Two of the extracted samples were dried over night at 100° C., two over night at 70° C., and two for 24 hours in vacuum desiccators to constant weight. The samples were then extracted with water, dried five hours at 100° C., and the loss in weight noted. Ammonium nitrate was determined in the water solutions by the distillation method previously described. The results are tabulated below:

Effect of different methods of drying ammonium nitrate explosives after ether extraction.

[Determinations by J. H. Hunter.]

Method of drying.	Loss of weight, per cent.						NH_4NO_3 in water solution, per cent.		
	Ether extraction.			Water extraction.					
	High.	Low.	Mean.	High.	Low.	Mean.	High.	Low.	Mean.
In a 100° oven	13.48	13.10	13.29	77.58	77.23	77.40	....	71.76	71.76
In a 70° oven	11.72	11.64	11.68	79.29	79.09	79.19	75.01	74.78	74.90
In a vacuum desiccator	11.68	11.57	11.63	79.22	79.11	79.17	75.31	75.20	75.25

These results show clearly that drying at 100° after extraction with ether causes a considerable loss of ammonium nitrate, most of the loss being due to decomposition of the nitrate by the zinc oxide.

The sum of the amounts of sodium nitrate, ammonium nitrate, and zinc oxide found in the water solution will be less than the total water extract, since the latter, as before noted, includes water-soluble organic material from the wood pulp, flour, or other carbonaceous absorbents. This organic material is added to the amount of starch, etc., removed by hydrolysis and reported as "starch," as has been noted on a previous page.

LOW-FREEZING DYNAMITE.

Nitroglycerin congeals or freezes at a temperature of about 8° C. (46° F.), and as nitroglycerin in the frozen condition is much less sensitive to the action of a detonator than when in the liquid condition, explosives containing frozen nitroglycerin usually fail to explode when attempts are made to use them.

As the outdoor temperature for several months in the year is on the average below the temperature at which nitroglycerin explosives freeze, many efforts have been made to prepare low-freezing explosives, which, without being thawed, may be used at temperatures lower than that at which ordinary nitroglycerin explosives are frozen. Some types of nonfreezing explosives contain ammonium nitrate mixed with nitrostarch, nitrotoluene, or similar material, but those explosives to which the term "low-freezing" is usually applied contain nitroglycerin mixed with the liquid nitrotoluenes, with crystalline dinitrotoluene or trinitrotoluene, with the nitrochlorhydrins or other materials, it having been shown, for example, that 20 per cent of dinitrochlorhydrin in nitroglycerin reduces the temperature at which the mixture will freeze to about —12° C.,[a] and by the use of mixtures of nitroglycerin and dinitrotoluene explosives are prepared which may be used at temperatures considerably below 0° C.

Many low-freezing explosives are marked with the designation "L. F." upon their wrappers; but even in the absence of this notice of the nature of the explosive a low-freezing dynamite may frequently be distinguished by the odor of nitrotoluene, or by the color test for nitrosubstitution compounds made on the ether extract as described under "Qualitative examination," on pages 17 and 18.

DETERMINATION OF NITROSUBSTITUTION COMPOUNDS.

With low-freezing dynamites the methods of sampling and of determination of moisture are carried out in the manner already outlined. The extraction with ether is also made in the usual manner, and one of the samples of ether extract is used, as outlined on a preceding page, for the determination of resins, sulphur, or other ingredients. The other sample of ether extract is used for the determination of the nitroglycerin and nitrosubstitution products.

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[a] Roewer, F. A., Proc. 6th Int. Cong. App. Chem., vol. 1, 1906, p. 541.

So far as is known by the writers, no satisfactory method has yet been found for the direct determination of nitrosubstitution compounds in the presence of nitroglycerin. The analysis of such mixtures is generally made by determining the nitroglycerin by means of the nitrometer (p. 35), and finding the amount of nitrosubstitution compound by difference. The nitrosubstitution compounds are not decomposed in the nitrometer as are the nitric esters.

It is interesting to note, however, that if mononitrotoluene is present the amount of nitroglycerin found by means of the nitrometer does not represent the true amount of this ingredient in the mixture. It has been found[a] that a portion of the nitric acid liberated from the nitroglycerin by the action of the sulphuric acid used in the determination is taken up by the mononitrotoluene present, the latter becoming quantitatively nitrated to dinitrotoluene. Thus, if the amount of nitroglycerin in the ether extract is not in excess of the theoretical amount required to yield sufficient nitrogen to convert all the mononitrotoluene to dinitrotoluene, no evolution of nitric oxide will result. In other words, the error in the determination of nitroglycerin is equal to about 0.5530 gram of nitroglycerin for each gram of mononitrotoluene present. Pure crystalline dinitrotoluene or trinitrotoluene was found to have no effect on the determination, and the same was found to be true of the so-called "liquid trinitrotoluene." "Liquid dinitrotoluene," however, causes an error amounting to 0.0628 gram of nitroglycerin for each gram of the nitrosubstitution product. This error was shown to be probably due to the presence of mononitrotoluene in the liquid dinitrotoluene.

These results show that the nitrometer method for determination of nitroglycerin is not reliable if mononitrotoluene is present. The latter is, however, seldom used in low-freezing dynamites, and in the case of the more commonly used liquid dinitrotoluene, the resulting error is not large. For example, in an explosive containing 25 per cent of nitroglycerin and 10 per cent of liquid dinitrotoluene, the error in the determination of nitroglycerin would amount to 0.628 per cent, or the amount of nitroglycerin found would be 24.37 per cent instead of 25 per cent.

Further information may be gained by determining the total nitrogen of both the nitroglycerin and the nitrosubstitution compound by a modification of the Kjeldahl method and deducting the nitrogen of the nitroglycerin, the difference being the nitrogen of the nitrosubstitution compound. From this nitrogen the amount of the latter can be calculated. This method is of value only if the nitrosubstitution compound has been identified by the preliminary examination.

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[a] Storm, C. G., The effect of nitrotoluenes on the determination of nitroglycerin by means of the nitrometer, Proc. 8th Int. Cong. App. Chem., vol. 4, 1912, p. 117.

Another method for the determination of the total nitrogen of such mixtures, as well as the ester nitrogen, is that of Berl and Jurrissen,[a] in which a so-called "decomposition flask" is used. By means of sulphuric acid and a small amount of mercury in a vacuum the decomposition of nitroglycerin or other nitric ester is effected and the resulting volume of nitrogen oxide (NO) measured. A second sample of the mixture is treated in the same manner after a preliminary oxidation with chromic acid and sulphuric acid, whereby the total nitrogen is converted to nitrogen oxide (NO). The difference between the two volumes of nitrogen oxide (NO) equals that resulting from the nitrosubstitution compound.

The remainder of the analysis—the extractions with water, acid, etc.—is conducted in the manner previously described and should present no further difficulties.

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[a] Berl, E., and Jurrissen, A. W., Über gasvolumetrische Analyse mit dem "Zersetzungskolben" und die Stickstoffbestimmung in rauchschwachen Pulvern. Zeitschr. angew. Chem., vol. 23, 1910, p. 241.

GRANULATED NITROGLYCERIN POWDER.

When ordinary dynamite is used in blasting any material of a consistency resembling that of earth or clay, little of the energy of the explosive does useful work, because the soft and compressible nature of the material blasted allows the greater part of the energy of the explosive to be used in compacting the material and in producing a cavity. Consequently, gunpowder has been largely used in all places where earth, clay, or other soft material was to be dislodged. In the blasting of the banks of railroad cuts there are often places where a soft, but somewhat consolidated material, intermediate between earth and hard rock, has to be blasted. Such a material might be a soft shale, for example, or a friable and easily crumbled sandstone, and for dislodging it neither ordinary blasting powder nor ordinary dynamite is particularly suitable. In the year 1876 E. Judson patented an explosive consisting of a low-grade gunpowder made by heating and mixing together coal, sulphur, sodium nitrate, etc., granulating the mixture, and then coating this non-absorbent granulated dope with a small amount of nitroglycerin. The proportion of nitroglycerin used—often as little as 5 per cent—was such that had it been absorbed by the grains of explosive it would not have been capable of detonation, but by remaining wholly or largely upon the surface of the grains the use of a detonator brought about its explosion and the simultaneous ignition of the gunpowder base which it covered. Such an explosive, as a result of the detonation of the nitroglycerin, produces an initial blow sufficient to crack and fissure the partly consolidated material in which it is placed. The action of the gunpowder mixture that forms the larger part of the explosive so heaves and moves the broken-up mass as to make easy its removal with steam shovels.

Granulated nitroglycerin powders, or "free-running" explosives, have been very much used in the excavation of earth and are commonly known as Judson powder (after the inventor), bank powder, or railroad powder. In the analysis of low-grade granular powder, moisture is determined by the standard method, and the usual method of extracting with ether is followed. In the ether extract are usually found large proportions of sulphur, rosin, etc., besides the nitroglycerin. The proportion of sulphur commonly used in low-grade granular powder is so considerable that usually it is not all removed by extraction with ether.

The determination of nitrates in the residue after ether extraction is made in the manner already outlined for ordinary dynamite; an additional extraction with carbon disulphide is necessary to remove the sulphur not extracted by means of ether.

As antacids are seldom added to low-grade granular explosives, the extraction with dilute acid may generally be omitted; but if the qualitative examination has indicated the presence of an antacid, its determination is made as already described.

The residue remaining after the extractions with ether, water, and carbon disulphide is usually bituminous coal, although charcoal or other carbonaceous material may be found. An examination under the microscope or with a hand magnifier will usually show with sufficient certainty the nature of the insoluble residue, and the presence of bituminous coal may generally be confirmed by a volatile-matter determination made by heating the solid residue in a small crucible over a Bunsen flame.

The separation and determination of the ingredients of the ether and water extracts is carried out by the methods previously described.

BLACK POWDER.

The general term "black powder" is applied to several explosives of nearly similar composition, including chiefly black blasting powder, black gunpowder, and black fuse powder. As their chemical examination involves identical problems, they are here treated as one general class.

Black blasting powder usually consists of a mixture of sodium nitrate, sulphur, and charcoal, whereas black gunpowder is generally a mixture of potassium nitrate, sulphur, and charcoal. The real difference between "gunpowder" and black blasting powder is one of use, since some blasting powder containing potassium nitrate as the oxidizing material has been made, and, similarly, there is record of gunpowder having been made from sodium nitrate. Although black blasting powder is usually made in larger grains than gunpowder, yet for certain purposes, particularly for large cannon, grains of gunpowder have been made even larger in size than the customary kinds of blasting powder, and again finely granulated blasting powder has been made for use where a quick-acting explosive, yet one not so rapid as dynamite, was desired.

The black-powder composition used in the ordinary miner's safety fuse and known as "fuse powder" is much similar to the ordinary grade of gunpowder, but is of very fine granulation (usually 40 to 100 mesh), and contains potassium nitrate as its oxidizing agent.

PHYSICAL EXAMINATION.

GRANULATION OR AVERAGE SIZE OF GRAINS.

The determination of the granulation of black powder is made by a series of standard sieves, but this examination is not usually required in connection with chemical analysis, and can be made only where a large sample of the powder is available. The standard sizes of grains of black blasting powder, together with a statement of the size of screen through which the material will pass, is given in the following tabulation:[a]

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[a] Munroe, C. E., and Hall, Clarence, A primer on explosives for coal miners. Bureau of Mines, Bull. 17, 1911, p. 17.

Relation between sizes of black blasting powder and separating sieve.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CCC	[illegible] inch	[illegible] inch
CC	[illegible] inch	[illegible] inch
C	[illegible] inch	[illegible] inch
F	[illegible] inch	[illegible] inch
FF	[illegible] inch	[illegible] inch
FFF	[illegible] inch	[illegible] inch
FFFF	[illegible] inch	(a) [illegible] inch

[a] Or 28-mesh bolting cloth.

GRAVIMETRIC DENSITY.

By "gravimetric density" is meant the "apparent specific gravity" of the explosive, or the ratio that the weight of the powder contained in a given volume bears to the weight of water that would exactly fill the same volume. Gravimetric density or apparent specific gravity is therefore not only a factor of the true density of the powder, but is also influenced by the size and the shape of the grains, since obviously the space occupied by voids, or the space between grains, must vary with the shape and size of the grains.

The standard determination of gravimetric density is made by pouring the powder into a vessel, usually in the shape of the frustrum of a cone, striking off with a straightedge all over that required to fill the measure, and then weighing the powder held by the receiver. Plate II, *B*, shows a commercial type of gravimetric balance for this purpose. With this balance direct readings of the gravimetric density of a powder are possible without calculation. When so few determinations must be made as to make the use of a separate instrument seem unnecessary, the determination of the weight of powder contained in a cylindrical graduate of known volume, or a standard pint or quart measure, may be made. In all cases the gravimetric density is the ratio expressed by dividing the weight of powder required to fill the measure even full by the weight of water from the same measure even full.

The gravimetric density of black powders varies over a considerable range, from about 1 to 1.3.

ABSOLUTE DENSITY.

By "absolute density" is meant the true specific gravity of the powder, the air space between grains being disregarded and only the density of the grains being considered. Owing to the fact that both sodium and potassium nitrates are readily soluble in water, it is not possible to make this determination with black powder by the picnometer method with water, so that a number of instruments involving the use of mercury have been designed by different investigators.

The form of instrument used by the Bureau of Mines is illustrated in figure 5, and was devised by one of the authors.[a] The apparatus consists of a reservoir and means for introducing within this reservoir a picnometer bottle containing the powder whose density is to be determined. By opening the water-supply valve the mercury is raised within the reservoir, and on closing it and opening the waste-pipe valve the water pressure is removed from the mercury in the lower reservoir. A Torricellian vacuum is thus created in the dome above the bottle; most of the air in the bottle escapes and is replaced with mercury. The operation is repeated until the air in the bottle is completely replaced. With this instrument the determination of the absolute density of black powder may be quickly and accurately made.

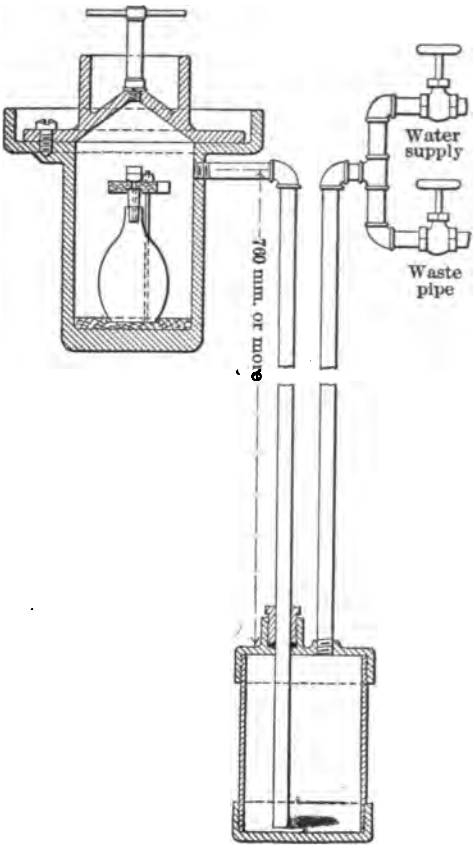

FIGURE 5.—Densimeter.

SAMPLING.

About 50 to 100 grams of the original sample is crushed in small portions in a porcelain mortar and passed through an 80-mesh sieve. All precautions are taken to avoid unnecessary exposure of the sample to the air during this treatment. If each portion is placed in a stoppered bottle as soon as sifted, there is no appreciable change in hygroscopic moisture content. The powdered sample is well mixed before its analysis is begun.

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[a] Snelling, W. O., Improved densimeter. Proc. 8th Int. Cong. App. Chem., vol. 4, 1912, p. 105. (Chem. Abs., vol. 6, 1912, p. 3524.)

CHEMICAL EXAMINATION.

The chemical examination of black powder consists essentially of the determination of the amounts of moisture, nitrate, sulphur, and charcoal present. The nitrate is readily separated from the sulphur and charcoal by the solvent action of water, and after the residue from water extraction has been carefully dried the sulphur may be readily separated from the charcoal by the action of carbon bisulphide, or other solvent.

The charcoal is always determined by difference. After being dried the charcoal is usually ignited and its content of ash determined.

DETERMINATION OF MOISTURE.

The determination of moisture is carried out exactly as has been described in the analysis of dynamite (p. 20), a 2-gram sample being spread on a 3-inch watch glass and desiccated for three days over sulphuric acid. It is customary in some explosives laboratories to determine moisture on a sample that is crushed only sufficiently to pass through a 10 to 12 mesh sieve, because in further pulverization the moisture content of the powder may be influenced by atmospheric conditions. Comparative determinations have indicated, however, that unless there is undue exposure in preparing the sample the difference in moisture content between the coarse and the finely powdered sample is slight, and since the nature of black powder is such that a finely powdered sample must be used for chemical analysis it is considered much more convenient to use the same for the moisture determination.

Many authorities recommend that moisture in black powder be determined by drying in an oven at temperatures of 60° to 100° C.[a] As sulphur is more or less volatile at temperatures even slightly above ordinary, the authors thought it advisable to compare the relative merits of oven drying with the desiccation method. A series of determinations was therefore made on large, well-mixed samples of finely ground powder (80-mesh), 2 grams spread uniformly in a thin layer on a 3-inch watch glass being used for each determination. The samples heated in ovens were allowed to cool for 15 minutes in desiccators before weighing. It was found necessary to make the weighings as rapidly as possible in order to prevent increase of weight. The following results were obtained.

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[a] Lunge, G., and Berl, E., Chemisch-technische Untersuchungsmethoden, vol. 3, 1910, p. 116; Guttmann, O., Schiess- und Sprengmittel, 1900, p. 48.

Results of determinations of moisture in black powder.

SAMPLE A.

[Determinations by W. C. Cope.]

Time.	Loss on desiccation over sulphuric acid.	Loss on drying at 70°.	Loss on drying at 100°.
Hours.	*Per cent.*	*Per cent.*	*Per cent.*
1	....	1.00	1.05
2	....	1.00	1.10
3	....	1.00	1.15
5	....	1.00	1.30
72	1.00	....	....

SAMPLE B.

[Determinations by C. A. Taylor.]

1	....	0.44	0.57
2	....	.46	.78
3	....	.50	.94
5	....	.54	1.07
7	....	.59	1.19
24	0.42—0.47	.74	3.70
72	0.46—0.49	....	....

The analysis (calculated moisture free) of sample B was originally as follows: Sodium nitrate, 74.07; sulphur, 10.09; charcoal 15.84. The sample dried 24 hours at 100°, with a loss of 3.70 per cent, was analyzed with the following result: Sodium nitrate, 77.0; sulphur, 6.53, charcoal 16.47. It is therefore evident that there is a loss of sulphur from black powder at 100°, and that this loss is appreciable in even a few hours' heating, whereas at 70° the loss for periods of heating up to five hours is approximately the same as the moisture determined by desiccation.

Desiccation gives practically constant weight in 24 hours, but as the loss of moisture takes place more slowly in coarser samples, a uniform period of three days has been adopted.

Sulphur alone is slightly affected by temperatures up to 100° C. A sample of approximately 5 grams of powdered brimstone (80-mesh) was desiccated for two days over sulphuric acid without loss of weight. It was then dried five hours at 70° C., losing only 0.003 per cent; further drying for five hours at 97° caused a loss of only 0.01 per cent.

EXTRACTION WITH WATER; DETERMINATION OF NITRATES.

In the determination of nitrates by extraction with water, about 10 grams of the finely ground sample is weighed in a Gooch crucible with asbestos mat and about 200 c. c. of water, in successive portions of 15 to 20 c. c. each, is drawn through the sample by means of suction. The complete solution of the nitrate is hastened by the use of warm or hot water, although 200 c. c. of cold water is usually sufficient. The final portions of water passing through the crucible should be tested for soluble nitrate by evaporation on a glass plate, or an excess of strong sulphuric acid containing a few crystals of diphenylamine may be added to a few drops of the water, and an intense blue coloration will indicate the presence of nitrate.

The extraction is made on duplicate samples as with dynamite. After the complete removal of the nitrate the crucibles containing the portion insoluble in water are placed in a drying oven at a temperature of about 70° and dried to constant weight, usually overnight, although five hours is generally sufficient. The percentage of loss of weight, minus the moisture content found as described above, represents the total water-soluble material, and includes, in addition to sodium or potassium nitrate, a small amount of water-soluble organic material from the charcoal and the impurities in the original nitrate, such as chlorides and sulphate. An aliquot portion of the water extract is evaporated to dryness on a steam bath, treated with a little nitric acid, again evaporated, heated to slight fusion, and weighed. (See p. 44.) For accurate analysis the amounts of chlorides and sulphates may be determined in separate portions of the water extract and the true nitrate content determined by difference, or a direct determination of nitrate may be made with the nitrometer on a portion of the extract, as previously described.

The water solution should, of course be tested to determine whether sodium or potassium nitrate is present. This determination is conveniently made by heating to redness a clean platinum wire dipped in the solution, and observing the color of the flame through several thicknesses of cobalt glass. Potassium is indicated by its characteristic red color, and the yellow of the sodium flame is entirely cut off by the blue glass. Without the cobalt glass a sodium nitrate powder should give an intense yellow flame and a potassium nitrate powder a pale pink or lavender flame. If both sodium and potassium nitrates are indicated, a determination of potassium is best made by the sodium-cobalti-nitrate method of Drushel,[a] or the proportions of sodium and potassium nitrates may be calculated with an approximate degree of accuracy from the total weight of nitrates found by evaporation and the percentage of nitrogen in the combined weight of these nitrates as determined by the nitrometer.

The following illustrates the method of calculation employed:

Let a = weight of both nitrates.
x = weight of sodium nitrate.
Then $a-x$ = weight of potassium nitrate.
Let b = percentage of nitrogen found in combined nitrates.
16.47 = percentage of nitrogen in sodium nitrate.
13.87 = percentage of nitrogen in potassium nitrate.

$$\text{Then } 0.1647x+0.1387\ (a-x)=\frac{ba}{100}.$$

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[a] Bowser, L. T., The determination of potassium by the cobalti-nitrate method. Jour. Ind. and Eng. Chem., vol. 1, 1909, p 791.

Solving for x gives the weight of sodium nitrate present in the mixture, and subtracting this from the total weight of the mixture gives the potassium nitrate.

EXTRACTION WITH CARBON DISULPHIDE; DETERMINATION OF SULPHUR.

The dried and weighed material left from the extraction with water consists of the sulphur and charcoal. The sulphur is determined by loss of weight on extraction with carbon disulphide in the Wiley extraction apparatus, the method being exactly the same as that used in the extraction with ether.

Because of the fact that it is difficult to obtain carbon disulphide that does not leave a residue of sulphur on evaporation, it is not customary to evaporate the carbon-disulphide extract to dryness and weigh the sulphur dissolved from the powder. This may be done, however, if freshly distilled pure carbon disulphide is used.

INSOLUBLE RESIDUE, CHARCOAL.

The residue remaining in the crucibles is weighed directly as charcoal after drying to constant weight at about 100°.

In drying the crucibles after the carbon disulphide extraction extreme care should be used to avoid setting fire to the inflammable vapor of the carbon disulphide, as it sometimes happens that the heavy vapor from the crucibles passes down to the flame by which the water oven is heated. Carbon disulphide has the lowest ignition temperature of any material not containing phosphorus, therefore in extracting with carbon disulphide, or in handling the crucibles after extraction, considerable care should be taken to avoid proximity to lights or fire.

DETERMINATION OF ASH.

The ash in the charcoal is determined by ignition over a Bunsen burner until all of the carbon has been burned off, and weighing. The ash is usually found to be about 0.5 to 1 per cent of the total powder. In case of an abnormally high ash value it is possible that the extraction with water was incomplete, leaving some nitrate undissolved.

The sulphur used in black powder is almost invariably brimstone, flowers of sulphur not being suitable for this purpose because of the invariable presence of acidity.

In those cases where flowers of sulphur are used, however, it should be noted that the extraction of the sulphur with carbon disulphide will be incomplete. Watts,[a] Gody,[b] and other authorities have called attention to the fact that flowers of sulphur always contain a considerable amount of insoluble amorphous sulphur, often amounting to as much as 35 per cent.

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[a] Watts's Dictionary of Chemistry, 1905, vol. 4, pp. 606–610.

[b] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 99.

Experiments made in the bureau's explosives laboratory with samples of brimstone and flowers of sulphur gave results as follows:

Relative solubility of flowers of sulphur and brimstone in carbon disulphide.

	Weight of sample.	Loss of weight on extraction.[a]	Insoluble substances.
	Grams.	*Grams.*	*Per cent.*
Flowers of sulphur	1.0907	0.7817	23.21
	1.0450	.7472	28.50
Brimstone	1.1238	1.1230	.07
	1.1004	1.0996	.07

[a] Extracted two hours in Wiley extraction apparatus with carbon disulphide.

In view of the fact that when flowers of sulphur are present the extraction with carbon disulphide is incomplete, some authors have recommended the use of hot aniline as a solvent for the sulphur.

The solubility of sulphur in various solvents is shown in the following table:[a]

Solubility of sulphur in 100 parts (by weight) of various solvents.

Solvent.	Temperature.	Parts (by weight) of sulphur dissolved.
	°C.	
Carbon disulphide	0	23.99
Do	15	41.65
Do	22	46.05
Do	38	94.57
Do	[a] 55	181.34
Benzene	26	.965
Do	71	4.377
Toluene	23	1.479
Ether	23.5	.972
Chloroform	22	1.205
Phenol	174	16.35
Aniline	130	85.96

[a] Boiling.

Of these solvents carbon disulphide and aniline are the ones that would appear to be of greatest practical value in analysis. Carbon tetrachloride, chloroform, and benzene have also been used with success as solvents for sulphur, but their use requires long-continued extraction.

Experiments have been made in the explosives laboratory of the bureau to determine the suitability of aniline as a solvent for sulphur in the analysis of black powder.

Extractions of both flowers of sulphur and brimstone with aniline heated to 130° to 140° showed only about 0.05 of 1 per cent insoluble material in each.

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[a] Gody, L., Traite théorique et pratique des matières explosives, 1907, p. 85. Biedermann, R., Chemiker Kalender, pt. 1, 1910, p. 291.

Several samples of black powder were analyzed, the sulphur being determined by means of extraction with hot aniline, and the results were compared with those obtained by the usual method of extraction with carbon disulphide. The extraction with the aniline was made by adding 10-c. c. portions of aniline, previously heated to 130° to 135° C. to the crucibles containing samples that had been extracted with water and dried in the usual manner, the hot aniline being drawn through by suction; this treatment was repeated from 5 to 12 times, using a total of 50 to 125 c. c. of aniline in different determinations. The last portions of aniline were removed by washing with a small amount of alcohol, and the residue dried at 100° C. The loss of weight was considered as the amount of sulphur present.

Comparative determinations of sulphur in black powder by extraction with carbon disulphide and aniline.

Sample No.	Sulphur extracted.	
	With carbon disulphide.	With aniline (130°).
1	13.64	13.79
2	9.99	9.72
3	7.81	7.74

Each of the above figures is the average of four to six closely agreeing results. This comparison shows that the aniline method gives very satisfactory results. Even as small an amount as 50 c. c. of aniline was found to be sufficient for complete extraction if each portion was allowed to stand a short time before sucking dry. The aniline may be readily recovered by distillation and used repeatedly.

A series of experiments were made to determine whether any difference in results would be effected by extracting the sulphur with carbon disulphide before the nitrate was extracted with water—that is, an inversion of the order of the extractions. A number of samples of black powder were analyzed by both methods with the results noted in the following tables. For comparison, determinations were made of the sulphur by precipitation as barium sulphate after oxidation with nitric acid and potassium chlorate.

Results of analyses of black powder.

[Samples A, B, and C analyzed by C. A. Lambert; sample D analyzed by C. A. Taylor.]

METHOD 1 (WATER EXTRACTION FIRST).

Sample.	Moisture.	Water extract.	Carbon disulphide extract.	Insoluble residue.	Sulphur determined as $BaSO_4$.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	0.16	69.76	13.64	16.44	13.55
	.16	69.73	13.55	16.56	
B	.21	74.07	10.09	15.63	10.05
	.21	74.27	9.89	15.63	
C	.36	78.88	7.87	12.89	7.89
	.36	78.98	7.68	12.98	
	.36	78.91	7.89	12.84	
D	.47	73.84	10.02	15.67	....
	.47	73.74	10.06	15.73	
	.47	73.79	10.04	15.70	

METHOD 2 (CARBON DISULPHIDE EXTRACTION FIRST).

A	0.16	69.58	13.74	16.52	13.55
	.16	69.57	13.80	16.47	
B	.21	73.97	10.39	15.43	10.05
	.21	73.92	10.44	15.43	
C	.36	78.45	8.47	12.72	7.89
	.36	78.54	8.49	12.61	
D	.47	73.91	10.15	15.47	....
	.47	73.74	10.25	15.54	
	.47	73.82	10.20	15.51	

It will be noted that in every case a greater loss was obtained on extracting with carbon disulphide when such extraction preceded the extraction with water than when it followed the extraction with water. That a more correct value for the amount of sulphur present is obtained by first removing the water-soluble portion of the powder, is shown by the results of the gravimetric determination of sulphur as barium sulphate. The latter results agree closely with the loss on extraction with carbon disulphide after removal of the nitrate.

The differences in results noted above are not readily explained. That both sodium and potassium nitrates are practically insoluble in carbon disulphide was shown by extracting a number of dried samples of each of these nitrates with this solvent, losses of only 0.01 to 0.05 per cent being obtained. It was further demonstrated that the small amount of moisture present in the powder samples at the time of the extraction with carbon disulphide was not the cause of the high results of method 2. This was shown by extracting several samples of black powder with carbon disulphide both before and after drying in vacuum desiccators. On correcting all results to the sample in original condition it was found that the loss on extraction was practically the same in both cases. The results are shown in the table following.

Effect of moisture in black powder on extraction with carbon disulphide before removal of nitrate.

[Determinations by C. A. Taylor.]

Sample.	Moisture.		Loss on extraction with carbon disulphide.	
	Original sample.	Desiccated sample.	Original sample.	Desiccated sample.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
E	0.30	....	13.82	13.93
F	.22	....	10.02	9.99
G	.32	....	7.94	7.92

The method adopted by the Bureau of Mines for the analysis of black powder is as follows:

BUREAU OF MINES METHOD OF ANALYSIS.

Moisture is determined by desiccating a 2-gram portion of the 80-mesh sample spread uniformly on a 3-inch watch glass for three days in a sulphuric-acid desiccator. Nitrates are determined by extraction with water, sulphur by extraction with carbon disulphide, and charcoal by weighing the dried insoluble residue. The soluble impurities (sulphates, chlorides, etc.) are determined separately and a direct determination of nitrate made by means of the nitrometer.

In the analysis of black powder, as in the analysis of all other explosives, the Bureau of Mines follows the standard methods outlined in this bulletin except when the presence of unusual constituents renders necessary additional separations or determinations or introduces new difficulties. As these conditions are seldom met in the analysis of the more simple explosives, such as dynamite and gelatin dynamite, but are not infrequently found in connection with short-flame explosives intended for use in coal mining, they will be taken up in a subsequent bulletin, which will consider the analysis of permissible explosives.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

BULLETIN 15. Investigations of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall, 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 44. First national mine-safety demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

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Bulletin 64

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE TITANIFEROUS IRON ORES
IN THE UNITED STATES
THEIR COMPOSITION AND ECONOMIC VALUE

BY

JOSEPH T. SINGEWALD, JR.

WASHINGTON
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PREFACE.

One of the problems that confronts American ironmasters is the efficient reduction of magnetite containing high percentages of titanium. From time to time the discovery of enormous bodies of workable titaniferous ore has been reported, and the available literature dealing with the geologic occurrence and the economic value of the titaniferous magnetites in the United States contains a mass of information that in part is based on incomplete observation and even on hearsay.

Although the supplies of nontitaniferous iron ore that are available in the United States are still to be measured by millions of tons, yet the approaching exhaustion of many high-grade deposits, the general acceptance by blast furnaces of ores lower in iron than those utilized 10 years ago, and the probability of even lower-grade ores being used in increasing quantities indicate that some large deposits of ore would be contributing to the needs of the country were it not for their titanium content. In an attempt to ascertain just what the economic possibilities of the larger deposits of titaniferous iron ore may be, the Bureau of Mines took up the study of the possible utilization of these ores through some concentrating process. The conduct of this investigation was assigned to Mr. J. T. Singewald, jr., and the results are presented in this report. Mr. Singewald was directed to pay especial attention to the possibility of utilizing titaniferous ores at a profit with present methods and devices and under existing conditions. He was authorized to study in detail the physical structure and chemical composition of the ores, as bearing on the problem of utilization, but not to undertake any detailed investigation of the origin and geologic distribution of the deposits.

It is to be regretted that the results of Mr. Singewald's careful study of the ores are chiefly negative. Some deposits of titaniferous iron ore are clearly not as extensive nor as high in iron as they were reported to be. Moreover, examination of many samples by metallographic methods has demonstrated that although a large part of the titanium in these ores is in the form of ilmenite, much of this ilmenite is far more intimately associated with the magnetite than has generally been supposed. Part of the magnetite and ilmenite occurs in such large and distinct aggregates that their separation by a magnetic concentration after fine crushing is practicable, but in by far the larger number of samples examined and in practically all the ore bodies that are known to be large enough and rich enough in iron to be of much importance, most of the ilmenite occurs as such fine intergrowths in the mass of the magnetite that a complete separation of the two minerals by any process based on difference of physical properties still seems impractical. Crushing even to 200 mesh would not insure a clean separation of the two minerals. Consequently the problem of utilizing titaniferous magnetites involves the application of chemical rather than physical methods. In short, the problem is not one of eliminating the titanium by milling but of reducing the ores directly by some smelting process.

Iron ores containing over 1 per cent of titanium are troublesome to smelt in the blast furnace. Though Rossi and other investigators have demonstrated the possibility of eliminating titanium through the formation of relatively fluid slags consisting of complex titanosilicates, there seems to be no inclination on the part of the ironmasters to adopt furnace practice to these conditions. However, as Mr. Singewald points out, it is practicable to use in blast-furnace mixtures small proportions of the concentrates from a magnetic separation of the titaniferous ores with little change in present methods and without danger of choking a furnace. The use of electricity in smelting offers other possibilities. The reduction of titaniferous ores in electrically heated furnaces and the production of iron-titanium alloys by a direct process are problems of such importance that the Bureau of Mines, in connection with its investigations of the treatment of ores and of more efficient methods of smelting, is undertaking experiments with these ores. The results of these experiments will be published in future reports of the bureau.

J. A. HOLMES.

THE TITANIFEROUS IRON ORES IN THE UNITED STATES; THEIR COMPOSITION AND ECONOMIC VALUE.

By Joseph T. Singewald, Jr.

INTRODUCTION.

The term "titaniferous magnetite" is used to designate those magnetic ores of iron that carry more than 2 or 3 per cent of titanium. Large and easily workable deposits of these ores occur in different parts of the world, and have attracted attention for many years. Under present furnace practice, however, the smelting of these ores is both difficult and expensive, and for that reason they are not accepted by furnaces, so that the deposits are practically worthless. The problem of finding a feasible method of utilizing these ores has naturally been attractive, and numerous attempts have been made to solve it.

Experiments to that end embrace two lines of investigation. The one that has been the more frequently tried is the elimination of the titanium from the ores, so as to make possible their smelting in the usual way. The other is the devising of a method of smelting by which titaniferous ores may be reduced as economically as are non-titaniferous ores. The former method involves a physical process, the latter a chemical process.

The measure of success attainable by the first method depends entirely on the relations between the iron and the titanium in the ore. Views in regard to these relations have been divergent. Some investigators have believed the titanium to occur as a part of the magnetite molecule, in which case, of course, any process of mechanical separation would be impossible. Others have believed that the titanium occurs as the mineral ilmenite, and that the ores are aggregates of magnetite and ilmenite. In this case a separation of the two minerals is theoretically possible. Magnetite is highly magnetic; ilmenite is nonmagnetic or only feebly magnetic. Crushing and magnetic concentration should separate them. Numerous experiments in magnetic separation have been made with various degrees of success, but rarely has more than a very imperfect separation been obtainable. In other words, some of the titanium exists in a separable form and some in an inseparable form, and the ratio between the two forms is different in different ores. The whole question as to the nature of the ores remains little understood.

The use of the metallographic microscope seemed to offer a means of determining the relations that exist between the titanium and the iron in these ores. In the winter of 1911, in the capacity of Henry E. Johnston scholar at the Johns Hopkins University, the author took up the study of the problem along these lines. The necessary apparatus and laboratory facilities were provided by the geological department of the university. Material for a preliminary study was very kindly furnished by Prof. J. F. Kemp from the collection of titaniferous ores made by him and contained in the collections at Columbia University. This material was supplemented by ores obtained from Mr. W. L. Cumings, of the Bethlehem Steel Co.

A study of this material yielded results warranting a more thorough investigation of the problem, and this was made possible through the Bureau of Mines, with which the author became connected in June, 1911. The summer of 1911 was spent in visiting the principal localities in the United States at which titaniferous iron ores occur, for the purpose of making systematic collections of material. The following winter was spent in a study of the collected material in the geological laboratory of the Johns Hopkins University where the author continued as a Johnston scholar. This report is an account of the results obtained.

The author wishes to express his appreciation to those who made possible the carrying out of this investigation and to those who rendered assistance during its progress.

THE UTILIZATION OF TITANIFEROUS IRON ORES.

As stated above, the problem of the utilization of the titaniferous iron ores can be attacked along two lines—first, by the use of metallurgical processes, involving the direct reduction of the ores; second, by the use of milling methods, involving the elimination of titanium from the ores. The progress that has been made along these lines is briefly stated in the following pages.

THE SMELTING OF TITANIFEROUS IRON ORES.

SMELTING IN THE BLAST FURNACE.

Notwithstanding extensive discussions of the subject from time to time, the possibilities of smelting titaniferous iron ores in the blast furnace are still undetermined. That such ores have been smelted and excellent pig iron made from them is well known. It is equally well established that in many such cases the consumption of fuel has been so great as to make the cost of the process excessive. At present there is a prejudice, justifiable or not, against the use of ores carrying more than 1 per cent of titanium. This prejudice is based chiefly on the belief that the ores require an undue amount of fuel to reduce them, and that they cause the accumulation of infusible titanium compounds that ultimately choke the furnace.

A historical review of the use of titaniferous iron ores shows that their use has gradually declined. In the early days of the Catalan forge and small charcoal furnaces it did not seem to make any particular difference whether an ore was titaniferous or not. Many deposits of titaniferous ores were worked and smelted without difficulty. This fact no doubt is explainable in part by the condition of the iron industry at that time. Some of the arguments that are used against the ores at present would have been of little weight in those days. The enterprises were small and the production of iron was of far greater moment than the cost of production. The early furnaces and forges were surrounded by virgin forests, and the amount of charcoal required was not considered an important factor. Later, as the furnaces increased in size and the expense of procuring charcoal became greater, the quantity of fuel required to produce a ton of iron had to be taken into consideration. As the higher the titanium content of an ore, the lower the possible iron content, the use of titaniferous ores was of itself equivalent to the use of lower-grade ores. Further, the slags produced from titaniferous ores in ordinary furnace practice are less fluid, and hence the furnace had to be run at higher temperatures. This method of operation caused the reduction of the titanium, a result that was favorable to the formation of infusible accretions of titanium in the furnace. Thus the use of titaniferous ores tended naturally to a high fuel consumption, and at times to the choking of the furnace. The prejudice against the ores became so great that finally no furnace would knowingly use them.

However, because the deposits of titaniferous ore are so numerous and so large, and the ores so low in phosphorus and sulphur, they have never ceased to attract attention and numerous experiments have been conducted looking to a means of utilizing them. During the sixties and seventies of the last century the subject was repeatedly discussed in the Journal of the British Iron and Steel Institute. Attention was called to the fact that these ores had been worked and were then being worked in a number of furnaces in Norway, Sweden, and England. At some of those furnaces the entire charge consisted of titaniferous ores, at others they were mixed with nontitaniferous ores. With the evolution of the modern blast furnace, however, all of these attempts have gradually been discontinued. A century ago there were 15 small charcoal furnaces in operation at Taberg in Sweden, but for a number of years the deposit has been wholly abandoned.

Probably the most extensively used of these ores in the United States were those of Lake Sanford, N. Y. A furnace with a daily capacity of 3 or 4 tons was built there in 1840. The furnace was subsequently enlarged, and a second furnace with a capacity of 12 to 15 tons was built. This remained in operation until 1856. The natural difficulties due to the inaccessible location of the enterprise were of themselves almost insuperable, so that its duration is rather remarkable apart from any difficulties due to the highly titaniferous character of the ores.

Two blast furnaces were erected on Bay St. Paul in 1873 by the Canadian Titanic Iron Co. to utilize the titaniferous ores of that part of the St. Lawrence region,[a] but were operated for only a few years. Under the most favorable circumstances 3,040 to 3,792 pounds of charcoal per ton of iron was required, and when the ore and the limestone had become wet or covered with ice, as much as 6,400 pounds was required. Harrington states that the experience in Sweden has been that in many cases more than twice as much charcoal is necessary than is required to smelt ordinary magnetites.

In most cases it seems that no attempt was made to adapt the furnace charges to the nature of the ores. It will be interesting, therefore, to review some of the results that have been obtained when such attempts were made.

David Forbes, who was connected with charcoal ironworks in southern Norway that used titaniferous ores, states[b] that the experience of the Scandinavian ironmasters has shown that the only objection to their use is that they require a large amount of charcoal, and hence their use is not profitable where other ores free from titanium can be obtained at a reasonable rate. For this reason he found it unprofitable to smelt alone an ore carrying 42.04 per cent Fe and 15.10 per cent TiO_2, but could readily use such an ore with equal parts of a nontitaniferous ore. In the attempts to smelt it more easily, he says, his predecessor, supposing that a volatile compound of silicon and titanium would be formed, fluxed the ore with increasing charges of stamped quartz until a cast iron was obtained so highly charged with silicon that "it flowed from the furnace like porridge." Forbes went to the other extreme in fluxing with lime so as to form a titanate of lime and obtained unsatisfactory results. Subsequently he found that by using both quartz and limestone as fluxes silicotitanates of much more fusible character were formed and more satisfactory results were obtained. When the amount of titanium in the ore did not exceed 8 per cent, or was reduced to 8 per cent by admixing other ores, no difficulty was experienced in working the ore cleanly and profitably.

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[a] Harrington, B. J., Notes on the iron ores of Canada and their development: Geol. Survey of Canada, Rept. for 1873–74, pp. 249–251.

[b] Forbes, David, On the composition and metallurgy of some Norwegian titaniferous iron ores: Chem. News, 1868, pp. 275–276.

An attempt made by the Norwegian Titanic Iron Co. to smelt highly titaniferous ores at Norton, England, met with failure after a few years' trial. W. M. Bowron, who was connected with the company as chemist, states[a] that "the process, regarded as a process, was a perfect success; but the enormous quantity of fuel required, the small quantity of iron in the ore, and the cost and uncertainty of importation militated seriously against its commercial success." The ores used by the company were composed of 36.33 per cent Fe and 39.20 per cent TiO_2. Nearly 3 tons of charcoal were required to produce 1 ton of iron. The smelting of such an ore is obviously not a fair test of what can be done with average titaniferous iron ores. A nontitaniferous magnetite carrying such a low percentage of iron would not be used in a blast furnace without previous concentration. The results are important in that they show the possibility of smelting even the highest titanium-bearing ores successfully, though not economically, in the blast furnace.

A very thorough study of the problem has been made in this country by Rossi. In 1890 he published[b] a review of what had been accomplished in the way of smelting titaniferous iron ores both in this country and abroad. Rossi's review, however, adds no essential facts to what has already been said. Three years later he published[c] the results of some experiments that he conducted. His experiments, made along the lines adopted by Forbes, were designed to discover easily fusible titanate slags of low viscosity. He first experimented with the formation of compounds that could be easily fused and liquefied. He then mixed ore charges to produce slags of such composition to determine whether pig iron could be made to separate from them. The results of these experiments are given in detail in the paper cited; it will be sufficient to state here that he obtained the best results with a tribasic slag, in which the bases were lime, magnesia, and alumina. The experiments were first conducted in a small furnace without forced draft; subsequently a small blast furnace was erected. The latter yielded pig iron and slags that showed good fluidity and fusibility, and there was no choking of the furnace with infusible titanium compounds. The ores experimented on ranged from 18.70 to 20.03 per cent TiO_2.

In 1895 the experiments were repeated by Rossi[d] on a larger scale in a furnace with a daily capacity of about 3 tons, no difficulties being experienced in running the furnace. These experiments showed that the most refractory slags could be melted without reducing silica, and hence much less titanic acid. Under the conditions of the experiments he says that furnaces can not be troubled with titanium deposits. "The deposits consist of cyano-nitride of titanium, which supposes for its formation not only the reduction in the furnace of titanic acid to titanium but the highest temperature and other conditions." He further says: "It may be argued that circumstances may so occur in the running of a blast furnace smelting any kind of nontitaniferous ores that would lead to an obstruction whose removal would require forcing the heat and the pressure of the blast, and that these circumstances in the special case of titaniferous ores would be favorable to the formation of titanium deposits by the reduction of the titanic acid." His reply to this is that the action of the blast furnace is so well understood and in such competent hands at the present time that such conditions are very rare; but if they should arise, it would be easy to change the charge to nontitaniferous ores until the obstruction has been removed and the furnace brought back to normal condition.

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[a] Bowron, W. M., The practical metallurgy of titaniferous ores: Trans. Am. Inst. Min. Eng., vol. 11, 1883, pp. 159-164.

[b] Rossi, A. J., Titanium in blast furnaces: Jour. Am. Chem. Soc., vol. 12, 1890, pp. 90-117.

[c] Rossi, A. J., Titaniferous ores in the blast furnace: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 832-864.

[d] Rossi, A. J., The smelting of titaniferous ores: Iron Age, 1896, vol. 1, pp. 354-356, 464-469.

In order to become familiar with the behavior of his furnace under normal charges, it was first run for a time on Lake Superior ores; these were then gradually replaced by titaniferous ores and the flux changed from calcite to a dolomite carrying 12 to 14 per cent of magnesia. The titaniferous ores consisted of four-fifths to five-sixths Sanford or Millpond ore and one-fifth to one-sixth Cheney Pond ore. Rossi's account of the results is given below:

> In order to judge the relative economy of these three runs under as nearly as possible similar conditions, we will compare the amounts of fuel and stone required per unit of pig metal when the furnace gave the greatest production in each case. This supposes, indeed, for the kind of ores or mixtures of ores considered, the most favorable conditions of running for each. By making precisely the same ample allowance of time in each case for stone and coke before each maximum cast of 24 hours as chargeable to that cast, we found the figures given below:

Results of Rossi's blast-furnace tests of different ores, based on unit quantity of pig iron when greatest production was obtained.

RUN NO. 1 WITH NONTITANIFEROUS HEMATITES FROM LAKE SUPERIOR.

Stone, unit quantity required	1.15
Coke, unit quantity required	2.15
Fe in ores, per cent	62
Maximum cast of iron in 24 hours, pounds	4,600

RUN NO. 2 WITH MIXTURE OF HEMATITE AND TITANIFEROUS ORES.

Stone, unit quantity required	1.19
Coke, unit quantity required	2.20
Fe in ores, per cent	56
Maximum cast of iron in 24 hours, pounds	5,035

RUN NO. 3 WITH TITANIFEROUS ORES FROM THE ADIRONDACKS.

Stone, unit quantity required	0.95
Coke, unit quantity required	1.99
Fe in ores, per cent	52
TiO_2 in ores, per cent	20
Maximum cast of iron in 24 hours, pounds	6,735

Hence, to say the least, the titaniferous ores, under the same conditions of furnace running, did not require any more fuel per unit of pig metal than excellent non-titaniferous ores. Really they required decidedly less, and the production of the furnace was increased considerably.

Summing up the results of his experiments, Rossi concludes:

1. As anybody who may desire to make the experiment can verify, titanic acid can form definite compounds, perfectly fusible, if properly fluxed, containing as much as 35 to 40 to 50 per cent of titanic acid, with alumina, lime, and magnesia as bases, and admissible as slags in blast-furnace work. Larger percentages still, such as 65 per cent, can enter into a compound and it remains fusible. The objections to the smelting of titaniferous ores on account of the refractory character of the slags are not sustained by our practice or that of others, or by direct experiments on the properties of these compounds.
2. In running a furnace under special conditions of temperature and pressure of blast no troubles have been experienced from the titanium deposits. We never observed any in our blast-furnace tests, and none are mentioned by Dr. Forbes in his practice in England and Norway.
3. If these special conditions of lower heat, considered more favorable in smelting these ores, are held to imply against them a waste of fuel, it is a question whether this is not offset by the smaller amount of cinder to melt, the lesser quantity of fluxes necessary and their indirect effect upon the productive capacity of the furnace, as well as the greater value of the pig metal obtained for specific and numerous applications. This is without taking into account the possibility of not submitting to it by a rapid driving and forcing the production, conditions which, to judge from our tests, could be easily realized with these ores.

However conclusive Rossi's experiments may appear, no attempts have been made to carry them out on a commercial scale; and the titaniferous ores remain in hopeless disrepute so far as their use in the ordinary blast furnace is concerned.

SMELTING IN THE ELECTRIC FURNACE.

Electric smelting of iron ores is still in its infancy, and its full possibilities have not yet been demonstrated. Where conditions are favorable it has met with considerable success. Electric smelting is of special interest in this connection since there is a confident feeling in many quarters that herein lies the hope of the utilization of the titaniferous ores. However, our knowledge in this regard has not yet reached the point where any very definite conclusions can be drawn.

Experiments in the electrical reduction of titaniferous iron ores have been conducted in Canada. About seven years ago, Haanel[a] carried out a series of experiments for the Canadian Government at Sault Ste. Marie in the smelting of Canadian iron ores by the electrothermic process, titaniferous iron ores being used in one of the experiments. Unfortunately this run, which was the last one made, was not as complete as the others. The furnace lining was in very bad condition, but as the time for making the experiments had nearly expired it could not be repaired and the run had to be stopped before figures as to output had been obtained. The ore used contained 17.82 per cent TiO_2, and the furnace charge consisted of 400 pounds of ore, 100 pounds of charcoal, 50 pounds of limestone, and 50 pounds of fluorspar. The slag produced was very fluid, and the statement is made that "likely the fluorspar in the charge could have been reduced considerably or omitted altogether."[b]

Abstracts from an article on this subject, recently published by Stansfield,[c] who has experimented along these lines, are quoted below:

> Although the possibility of the electric smelting of iron ores for pig iron can not be definitely settled in a general way, there appears to be every probability that a process which yields steel instead of pig iron would be commercially possible in favorable localities. Steel could be made by smelting titaniferous iron ores in an electric furnace with a somewhat smaller amount of charcoal than would be needed for making pig iron, and the resulting metal could be transferred in the molten condition to an electrical steel-refining furnace, where it could be made into finished steel. The cost of producing the crude steel from the ore would be little more than that of producing pig iron, and the cost of refining the steel would be only a moderate addition to this, while the price obtainable for the finished product would be decidedly higher than could be obtained for pig iron.
>
> The writer has been associated with Mr. J. W. Evans in the development of a process in which the reduction of titaniferous ores to metal and the subsequent refining of the steel is carried out in a single furnace, and while the details of the furnace construction and certain parts of the operation have not yet been fully worked out the results have been so encouraging that it appears to be worth while to develop the process on a small working scale. With regard to the results so far obtained, it may be stated that titaniferous ores obtained from the Orton mine and containing about 7 per cent of titanium have been smelted directly to steel, and that such steel, containing about 1 per cent of carbon, has been found to possess unusually good qualities as a tool steel. The cost of smelting these ores and refining the steel can be determined fairly accurately from the figures published in regard to the electrical smelting of iron ores to pig iron and the electrical refining of molten steel. These figures are more dependable than data obtained from the small-scale experiments that have so far been made. The writer intends, however, in the near future to

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[a] Haanel, Eugene, Report on the experiments made at Sault Ste. Marie, Ontario, under Government auspices in the smelting of Canadian iron ores by the electrothermic process: Canada Dept. of Mines, Mines Branch, 1907, pp. 85-86.

[b] Haanel, Eugene, Preliminary report on the experiments made at Sault Ste. Marie, Ontario, under Government auspices in the smelting of Canadian iron ores by the electrothermic process: Canada Dept. of Mines, Mines Branch, 1906, p. 19.

[c] Stansfield, Alfred, Electric smelting of titaniferous ores: Can. Min. Jour., vol. 33, 1912, pp. 448-449.

make further experiments on the reduction and refining of the steel in order to obtain direct information as to the cost of the process.

There does not appear to be any definite limit as regards the percentage of titanium in ores suitable for this process, but the cost of smelting will, of course, increase with the proportion of titanium, both on account of the cost of fluxing it and on account of the smaller proportion of steel obtained. It seems probable, therefore, that the process will be applied to ores that do not contain more than 5 to 10 per cent of titanium. Ores somewhat richer than this in titanium may be concentrated magnetically, so as to obtain a product which shall be at once richer in iron and poorer in titanium, and it may even be possible in some cases that the tailings from such a concentration process may be sufficiently rich in titanium to be smelted for ferrotitanium. Some ores containing too much titanium for steel making are not amenable to magnetic concentration, and these may be smelted with suitable admixture of nontitaniferous ores. It has been found that the electric furnace is more suitable than the blast furnace for the treatment of pulverized ores and that magnetic concentrates can be smelted alone or with the addition of a moderate proportion of coarser ore.

The use of titaniferous ores for making tool steel would appear to be very advantageous commercially, but can not be expected to provide for a large consumption of these ores, and it is of interest to consider whether the process can be applied to the production of steel on a larger scale. One purpose for which this process would appear to be very suitable is for the production of steel castings. A good deal of difficulty is experienced in the production of steel castings which can be relied upon as being entirely sound, and ferrotitanium is used in some cases for producing soundness in steel castings. It seems very probable, therefore, that steel made directly from titaniferous ores will be particularly suitable for the production of steel castings, and this will afford a larger field for the electric smelting of these ores. With regard to the use of this process on a still larger scale—for the production of steel rails, for example—the writer would say that there appears to be no definite reason why rails should not be made by this process, but would not care to speak definitely with regard to this until the process has been in operation on a working scale.

At least there has been opened a new field of investigation, in which the solution of the problem of the utilization of the titaniferous iron ores may be found.

ELIMINATION OF TITANIUM BY MAGNETIC CONCENTRATION.

The fact that many titaniferous magnetites are granular aggregates of magnetite and ilmenite is quite apparent to the naked eye in many of the coarser-grained ores. The highly lustrous rougher surface of the ilmenite can be easily distinguished from the duller black cleavage faces of the magnetite. This difference is brought out more plainly if the specimen is immersed for a time in concentrated hydrochloric acid, which acts on the magnetite but does not affect the ilmenite. The magnetite becomes still duller and pitted as a result of the solvent action of the acid, whereas the ilmenite remains unchanged. The relations between the magnetite and the ilmenite grains are brought out still more clearly if the specimen is ground down to a plane surface, polished, and treated with hydrochloric acid.

The polished ilmenite grains retain their luster, whereas the polished magnetite loses its luster and assumes a dull black. Specimens of ore that have been treated in this way are shown in Plate II, *B*, *C*, *D*, *E*, and *F* (p. 50), Plate VIII, *B* (p. 106), and Plate IX, *B* (p. 110).

Newland[a] applied this treatment to some of the Adirondack ores. Commenting on the results obtained, he says:

> In the specimens that have been examined the magnetite and ilmenite are distinguishable without difficulty. There is a clear separation of the particles and no notable tendency toward intergrowth or inclusion on the part of either. The boundaries are sharp. Both minerals belong to the same order of crystallization, though the ilmenite seems to have begun to form somewhat earlier than the magnetite. The latter being commonly in excess constitutes the groundmass through which the ilmenite is more or less regularly distributed in grains of fairly even size.

A great many of the bright ilmenite grains have been isolated and tested with a magnet, and in every case were found to be practically nonmagnetic. Dull grains of magnetite similarly tested have in every case been found to be highly magnetic. Further the specimens mentioned above bear out Newland's statement that there is "no notable tendency toward intergrowth or inclusion on the part of either." Although there are numerous small grains of ilmenite scattered over the surface of the magnetite, they form an insignificant part of the total visible ilmenite; and nearly all of the ilmenite grains in the coarse granular ores are of sufficient size to be separated from the magnetite by crushing to a size allowable in actual commercial operations. If all of the titanium in titaniferous magnetites were contained in these ilmenite grains, magnetic concentration ought to give concentrates practically free from titanium. Some results that have actually been obtained in attempting to make a magnetic separation of the titanium are presented below:

RESULTS OF MAGNETIC-SEPARATION EXPERIMENTS.

The results of magnetic separations of foreign titaniferous magnetites are tabulated first; these are followed by a tabulation of the results of separations of ores from the United States. The latter results are also discussed subsequently. Pope[b] made three tests of ores from eastern Ontario. The experiments were made with a Wetherell magnetic concentrator at Newark, N. J. The ore was crushed so that it would pass through a 40-mesh screen but not through a 60-mesh screen.

No separation of Eagle Lake ore was possible. As soon as the current was strong enough to pick up a single particle all were picked up. This ore analyzed 64.68 per cent Fe and 6.41 per cent TiO_2.

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[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, 1908, pp. 151-152.

[b] Pope, F. J., Investigation of magnetic iron ores from eastern Ontario: Trans. Am. Inst. Min. Eng., vol. 29, 1899, pp. 372-405.

The results with Pine Lake ore are tabulated below:

Results of magnetic concentration of Pine Lake ore.

	Current.	Weight.	Fe.	TiO_2.
		Grams.	*Per cent.*	*Per cent.*
Ore	Single dry cell	380	43.38	13.52
Heads		272	56.45	18.10

The result of the concentration was to increase the metallic iron by ten thirty-thirds and the titanic oxide by eleven thirty-thirds.

The results with Chaffey ore were as follows:

Results of magnetic concentration of Chaffey ore.

	Current.	Weight.	Fe.	TiO_2.
	Amperes.	*Grams.*	*Per cent.*	*Per cent.*
Ore	0.25	720	53.0	7.4
Heads		640	56.1	5.0
Tails		73	27.0	29.9

Here the iron was increased 6 per cent and the titanium reduced 32 per cent by the concentration.

The results of many magnetic concentrations, principally of Norwegian ores, have been tabulated by Vogt,[a] as shown below:

Results of magnetic concentration of titaniferous iron ores from Heindalen.

Test designation.	Composition of ore.	Yield of concentrate.	Composition of concentrate.
	Per cent.	*Per cent.*	*Per cent.*
[b]	7.08 TiO_2 44.66 Fe 0.95 S 0.013 P	49.02	1.49 TiO_2. 68.51 Fe. 0.097 S. 0.006 P.
b [c]	6.20 TiO_2 35.85 Fe 0.023 P	35.46	1.30 TiO_2. 67.73 Fe. 0.004 P.
c [c]	4.90 TiO_2 27.65 Fe 0.042 P	23.98	0.72 TiO_2. 69.90 Fe. 0.003 P.

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[a] Vogt, J. H. L., Norges Jernmalmforekomster: Norges Geologiske Undersokelse 51, 1910, pp. 31-34. A German review by Vogt is contained in the Zeitschr. prakt. Geol., 1910, pp. 62-64.

[b] Represents a large-scale test made by a company in Stockholm.

[c] Represents laboratory test made by Prof. Henry Louis.

Results of magnetic-concentration tests by Farup.

Test designation.	Composition of ore.	Effects of crushing ore to 1 mm.		Effects of crushing ore to 0.1 mm.	
		Yield of concentrate.	Composition of concentrate.	Yield of concentrate.	Composition of concentrate.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	7.15 TiO_2 35.07 Fe	46.51	....	34.97	0.40 TiO_2. 69.60 Fe.
B	8.48 TiO_2 42.61 Fe	65.79	....	50.00	0.96 TiO_2. 68.40 Fe.
C1	4.32 TiO_2 21.33 Fe	28.01	....	20.92	1.03 TiO_2. 66.34 Fe.
C2	6.60 TiO_2	54.05	3.97 TiO_2	33.22	1.22 TiO_2.
C3	6.30 TiO_2	58.82	2.65 TiO_2	42.02	1.16 TiO_2. 67.59 Fe.
C4	7.21 TiO_2	50.50	4.23 TiO_2	36.63	1.47 TiO_2. 67.4 Fe.
C5	6.81 TiO_2	64.10	3.33 TiO_2	47.62	1.53 TiO_2. 65.68 Fe.
D1	9.03 TiO_2 49.3 Fe 0.81 S 0.017 P	75.19	5.00 TiO_2 62.24 Fe	63.29	1.24 TiO_2. 68.82 Fe.
D2	8.21 TiO_2 46.44 Fe 1.02 S 0.014 P	60.60	....	50.25	1.20 TiO_2. 68.70 Fe. 0.45 S. 0.008 P.
D3	7.80 TiO_2 51.20 Fe	69.93	4.09 TiO_2 61.38 Fe	63.69	2.35 TiO_2. 64.59 Fe.
E	5.48 TiO_2 62.0 Fe	90.90	2.39 TiO_2 68.17 Fe	87.72	1.60 TiO_2. 69.65 Fe.
F	32.9 TiO_2 45 Fe [a]	24.39	4.27 TiO_2 63.65 Fe	19.23	1.75 TiO_2. 68.1 Fe.
G	15.04 TiO_2 50 Fe [a]	59.17	....	47.17	2.37 TiO_2. 68.60 Fe.
H	13.55 TiO_2 40 Fe [a]	65.36	10.01 TiO_2 47.34 Fe	47.85	4.81 TiO_2. 60.99 Fe.
I1	13.49 TiO_2 50 Fe [a]	81.97	....	53.48	6.26 TiO_2. 59.07 Fe.
I2	10.87 TiO_2 50 Fe [a]	71.94	....	41.67	6.53 TiO_2. 55.16 Fe.
K	14.10 TiO_2	77.52	14.52 TiO_2	67.57	9.18 TiO_2.
L	7.78 TiO_2 49.52 Fe	76.92	8.02 TiO_2 53.72 Fe	65.79	7.9 TiO_2. 57.2 Fe.
M	9.80 TiO_2 41.2 Fe	71.43	12.98 TiO_2	62.89	10.80 TiO_2.

[a] Approximate.

Tests A, B, C, etc., represent ores from different deposits; C1, C2, C3, etc., represent ores from different places in the same deposit. A, B, and C represent ores from Heindalen, D from Rödsand, F from Laxedal in the Ekersund-Soggendal district, G from Solnor, and I from Lied. The sources of the others are not given.

Commenting on the results of these tests, Vogt says that "the so-called titanomagnetite in these tests consists of a mechanical mixture of magnetite and ilmenite. Whether the magnetite contains a small amount of TiO_2 in chemical combination is an open question. It is not probable, however, as the investigations show that the finer the crushing, the greater the quantity of titanic acid removed." In the cases of tests G, H, and I he regards the intergrowth to have been somewhat finer than in tests A, B, C, and D; and in K, L, and M he considers that much of the intergrowth was of microscopic size. Whether at the time of the solidification of the magmas primary magnetite and primary ilmenite crystallized, or whether at that time a magnetite formed that at high temperature contained ilmenite in solid solution, the ilmenite subsequently segregating at lower temperatures, he says can not yet be decided.

In addition to the above tests, Vogt gives the results of several tests made on magnetic sands. The results of one of these are presented below:

Results of magnetic-concentration tests of magnetic sand from Lofoten Islands, Norway.

[Size of sand grains—73.3 per cent less than one-quarter mm. but greater than one-sixth mm.; 26.7 per cent less than one-sixth mm.]

Determined constituents of sand.	Amount.	Condition of sand.					
		Not crushed.		Crushed to less than ⅙ mm.		Powdered.	
		Concentrate.	Tailings.	Concentrate.	Tailings.	Concentrate.	Tailings.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
TiO_2	13.20	5.03	26.90	3.14	26.7	2.5	....
Fe	56.55	67.70	43.56	69.24	43.59	70.33	....
P	.06	.045	....	.026	....	....	....
S	.007	.002	....	.002	....	....	....
SiO_2	3.52	.85	....	.250	....	....	....
Percentage of whole	....	53.8	46.2	50.5	49.5	47.7	52.3

The tests were made by a company in Stockholm, Sweden, as were also the first two in the table following. The third was made under the direction of Prof. Vogt with a Gröndal separator No. 5. Concentrate 1 was made without crushing the sand. This concentrate was then crushed to one-sixth mm. and a second separation made from it.

Results of magnetic-concentration tests of sands from lower St. Lawrence, Canada.

Quality of sand.	Composition of sand.	Amount of concentrate 1 obtained.	Composition of concentrate 1.	Amount of concentrate 2 obtained from 1.	Composition of concentrate 2.	Composition of tailings 2.
		Per cent.		*Per cent.*		
Lean	6.7 TiO_2 18.6 Fe	10.9	4.4 TiO_2 65.6 Fe	89.4	2.9 TiO_2 69.8 Fe	30.1 Fe.
Rich	18.6 TiO_2 54.8 Fe	42.2	2.3 TiO_2 69.6 Fe	96.6	1.5 TiO_2 70.5 Fe	44 Fe.
——	7.9 TiO_2 29.4 Fe	26.5	3.9 TiO_2 66.3 Fe	95	2.0 TiO_2 69.6 Fe	37 Fe.

The results of magnetic concentrations of titaniferous iron ores of the United States are presented below. They are a tabulated summary of the results discussed in a subsequent section of this report. The first table gives the results of tests previously made and the second of tests made by the author in the course of this investigation.

In the author's tests small samples of ore were crushed in a diamond mortar to pass through a 50-mesh screen having an opening of 0.3 mm. The crushed material was sorted into two sizes with a 100-mesh screen having an opening of 0.15 mm. Each size was then subjected to magnetic separation under water with a hand magnet. The resulting concentrates and tailings were analyzed for Fe and Ti by A. C. Fieldner, of the Bureau of Mines. The composition of the original ore was calculated from the ratio of concentrates to tailings.

Results of magnetic separations previously made.

Source of ore.	Size of screen passed through.	Determined constituents of ore.		Determined constituents of concentrate.		Determined constituents of tailings.	
		TiO_2.	Fe.	TiO_2.	Fe.	TiO_2.	Fe.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sanford, N. Y				4.00	62.66	47.50	38.86
Do	40-mesh	14.0	60.58	8.93	60.43	45.23	45.78
Do				9.66	60.60	32.22	42.84
Do.[a]	16-mesh			5.25	63.00		
Do	40-mesh			[b] 5.90	[b] 65.02		
Do				11.00	61.04		
Tuscarora, N. C		15.35	41.95	1.27	67.60	16.20	21.63

[a] From concentrate of ore mentioned just above.

[b] Average of two analyses.

Results of magnetic separations made by the author.

Source of ore.	Determined constituents of ore.		Effect of crushing ore to 0.3 mm.					Effect of crushing ore to 0.15 mm.		
			Yield of concentrate.	Determined constituents of concentrate.		Determined constituents of tailings.		Yield of concentrate.	Determined constituents of concentrate.	
	TiO_2.	Fe.		TiO_2.	Fe.	TiO_2.	Fe.		TiO_2.	Fe.
	P.ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Lincoln Pond, N. Y	5.88	64.66	96.0	4.82	66.08	31.45	30.59	95.6	5.12	66.27
Sanford, N. Y	19.02	55.07	78.2	11.15	61.23	47.20	32.99	75.9	10.47	61.23
Millpond, N. Y	18.02	54.47	83.2	13.18	58.89	43.03	32.74	85.3	12.28	59.17
Tuscarora, N. C	12.82	58.07	71.5	4.25	67.76	34.32	33.76	70.1	3.64	68.41
Iron Lake, Minn	24,30	53.30	93.3	23.15	54.93	40.37	30.59	92.0	23.58	54.13
Iron Mountain, Wyo	21.75	52.31	84.2	18.30	56.75	40.12	28.74	83.6	17.25	56.75
Do	19.47	54.48	77.7	12.58	60.76	43.47	32.61	76.0	10.32	61.97
Do	21.85	51.93	87.3	20.03	55.35	34.33	28.43	86.5	30.03	55.44
Shanton Ranch, Wyo	21.08	51.50	84.7	17.85	55.05	38.93	31.83	82.2	17.85	55.63
Do	19.98	52.98	84.1	17.22	56.93	34.58	31.96	78.6	16.72	57.30
Iron Mountain, Colo	14.50	51.96	86.0	13.50	56.93	20.97	21.42	80.4	13.10	57.77

The table following is compiled from the two preceding tables. It gives the amount of titanium per unit of iron in the ore and in the concentrates, and where known the size to which the ore had been crushed. From these ratios the percentage reduction of titanium per unit of iron is calculated. It is recognized that the results of such a calculation are not strictly comparable. The percentage of iron given by analysis is the total iron content. Some of this iron is present in the iron-bearing minerals of the gangue, and is not associated with the titanium, and these minerals are practically removed from the concentrates. The ratio of titanium to iron in the concentrates is therefore the ratio of the titanium to the iron with which it is actually associated, whereas the ratio of titanium to iron in the ore is the ratio of the titanium to the iron with which it is associated plus the iron contained in the gangue minerals. The iron contained in the gangue is removed in the magnetic concentration of ordinary magnetic ores, and this process does not bear on the problem of eliminating titanium from titaniferous magnetite. The presence of iron in the gangue lowers the calculated ratio of titanium to iron in the ore, and hence the calculated percentage of titanium removed per unit of iron is less than is actually the case. The leaner the ore the greater the discrepancy. For this reason, the percentage of iron present in the crude ore is included in the table.

Summary of results of magnetic separations.

FOREIGN ORES.

Source of ore.	Ore.		Concentrate.		
	Fe.	Ti per unit Fe.	Maximum size of grain.	Ti per unit Fe.	Reduction of Ti per unit Fe.
	Per cent.	*Per cent.*	*Mm.*	*Per cent.*	*Per cent.*
Eagle Lake	64.68	0.0595	[a] 0.3	0.0595	0
Pine Lake	43.38	.1870	[a] .3	.1924	[b] 3
Chaffey	53.0	.0838	[a] .3	.0537	36
Heindalen *a*	44.66	.0951	....	.0130	86
Heindalen *b*	35.85	.1038	....	.0115	89
Heindalen *c*	27.65	.1063	....	.0062	94
Heindalen A	35.07	.1223	.1	.0035	97
Heindalen B	42.61	.1194	.1	.0084	93
Heindalen C1	21.33	.1215	.1	.0093	92
Rödsand D1	49.3	.1099	.1	.0108	90
Rödsand D2	46.44	.1061	.1	.0105	90
Rödsand D3	51.20	.0914	.1	.0218	76
E	62.0	.0530	.1	.0138	74
I axedal F	[a] 45	.4387	.1	.0154	96
G	[a] 50	.1805	.1	.0207	89
H1	[a] 40	.2032	.1	.0473	77
I1	[a] 50	.1619	.1	.0636	61
I2	[a] 50	.1304	.1	.0710	46
L	49.52	.0943	.1	.0829	12
Lofoten	56.55	.1401	.2	.0272	81
St. Lawrence (lean)	18.6	.2161	.2	.0249	89
St. Lawrence (rich)	54.8	.2036	.2	.0128	94
St. Lawrence	29.4	.1612	.2	.0172	89

UNITED STATES ORES.

Source of ore.	Fe.	Ti per unit Fe.	Maximum size of grain.	Ti per unit Fe.	Reduction of Ti per unit Fe.
Sanford	60.58	0.1388	[a] 0.3	0.0886	36
Tuscarora	41.95	.2195	....	.0113	95
Lincoln Pond	64.66	.0546	.15	.0464	15
Sanford	55.07	.2072	.15	.1026	50
Millpond	54.47	.2005	.15	.1245	38
Tuscarora	58.07	.1324	.15	.0319	76
Iron Lake	53.30	.2735	.15	.2614	5
Iron Mountain, Wyo	52.31	.2495	.15	.1824	27
Do	54.48	.2144	.15	.0999	53
Do	51.93	.2544	.15	.2168	15
Shanton	51.50	.2456	.15	.1925	22
Do	52.98	.2263	.15	.1750	23
Iron Mountain, Colo	51.96	.1674	.15	.1361	18

[a] Approximate. [b] Increase.

The results of magnetic concentrations just cited show that the relations between the iron and the titanium in the titaniferous magnetites are not as simple as a megascopic examination of the ores would indicate. It is evident that a large part of the titanium is contained in the magnetite itself. The variation in the degree of separation obtained in the different cases shows further that the percentage of ilmenite in separable form and that present in inseparable form is not constant, but varies over a wide range. The only advantage to be derived from magnetic concentration of these ores, in so far as the titanium is concerned, is that in some cases the percentage of titanium can be brought low enough to make practicable the mixing of the concentrates with two, three, or four parts of nontitaniferous ores, whereby the titanium content would be made negligible.

MICROSTRUCTURE OF TITANIFEROUS MAGNETITE.

PREVIOUS INVESTIGATIONS.

It has been shown that in most titaniferous magnetites that have been subjected to magnetic concentration a large percentage of the titanium occurs in the magnetite in a form not separable from the magnetite by that process and not visible to the naked eye. That seemingly homogeneous magnetite crystals can contain a high percentage of titanium has been recognized for many years, and the manner in which it occurs in the magnetite has been the subject of considerable speculation. Fifty years ago Knop[a] analyzed some magnetite octahedra from Meiches in the Vogelsberg, and found 24.95 per cent of TiO_2; and Kemp[b] says that O. A. Derby has mentioned to him the occurrence of natural loadstone in Brazil with 20 per cent of TiO_2. A sample of seemingly pure magnetite picked from a specimen of Lake Sanford ore contained 11 per cent of TiO_2.[c]

In 1858 Rammelsberg[d] expressed the view that the titanium-bearing magnetites consist of mixtures of titanium-free octahedral magnetite and rhombohedral ilmenite. Since that time a number of workers have recognized microscopic intergrowths of magnetite in ilmenite.

Though the intergrowths of ilmenite and magnetite are far more common, intergrowths of rutile and magnetite were discovered about the same time. Thus in 1877 Seligmann[e] described regular intergrowths of rutile in magnetite crystals from the Alp Lercheltiny in

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[a] Knop, A., Ueber titansäure—haltigen Magneteisenstein: Liebig's Ann. chem. pharm., vol. 123, 1862, p. 352.

[b] Kemp, J. F., The titaniferous iron ores of the Adirondacks: U. S. Geol. Survey 19th Ann. Rept., pt. 3, 1899, p. 386.

[c] See p. 76.

[d] Rammelsberg, C., Ueber die Zusammussetzung des Titaneisens, sowie der rhomboëdrisch und oktaëdrisch Krystallisirten Eisenoxyde überhaupt: Pogg. Ann., vol. 104, 1858, pp. 497–552.

[e] Seligmann, G., Mineralogische Notizen: Groth Zeitschr. für Kryst. und Min., vol. 1, 1877, pp. 340–342.

Binnenthal, Switzerland. About the time that the microscopic intergrowths of magnetite in ilmenite were first discovered Cathrein[a] described a regular microscopic intergrowth of rutile in magnetite analogous to the macroscopic intergrowth described by Seligmann. He found that on dissolving the magnetite in hydrochloric acid there was left behind an aggregate of minute rutile microlites arranged parallel to the three edges of an octahedral face and intersecting each other at an angle of 60°. The magnetite itself appeared black and opaque, wholly homogeneous, and even great magnification failed to reveal the intergrown rutile.

Neef,[b] describing a diabase, says:

> Accessory constituents are pyrite and a black ore showing on the surface of the section distinct systems of lines cutting each other at acute angles which seem to indicate intergrowths of ilmenite lamellæ. On etching the section with hot hydrochloric acid the ore readily dissolved, leaving behind an undecomposed latticework skeleton of ilmenite. Is this perhaps an intergrowth of specularite or magnetite with ilmenite lamellæ cutting each other at acute angles?

The same observation was made by Küch[c] a few years later in studying some West African rocks. He says in the description of a plagioclase-olivine-augite rock:

> On treating a thin section with hydrochloric acid the magnetite goes into solution. There remains behind, however, a latticework skeleton formed of laths which must be ilmenite, and which as such are lacking in the unetched section. This relation seems to point to intergrowths of ilmenite and magnetite, the latter being dissolved through the treatment with acid, so that only the ilmenite lamellæ remain. The same phenomenon has already been observed by Neef in a Swedish diabase.

About the same time a similar conclusion was reached by Teall[d] from a somewhat different consideration. His article was read in June, 1884, but refers to the one by Küch just quoted. He found an opaque iron oxide which carried considerable TiO_2 and was yet attracted by a weak bar magnet. The analysis and the physical properties of the substance, he believed, agreed with the assumption of a mixture of magnetite and ilmenite. To corroborate such an assumption he refers to the work previously cited, and to the fact that in the whin sill the substance alters into leucoxene along two sets of parallel planes. He concludes, therefore, that an intergrowth of magnetite and ilmenite actually exists.

The first mention of a microscopic intergrowth of magnetite and ilmenite was made by Becke[e] in 1886. He found that spheres of magnetite produced from octahedra from Pfitsch, Tyrol, Austria, were not homogeneous, but filled with tablets of ilmenite which were intercalated in the magnetite parallel to the octahedral faces. A year later Cathrein[a] described the same phenomenon more fully in the case of magnetite crystals from the Zillerthal, Tyrol, Austria. He found scattered over the octahedral faces of the magnetite small laths, 1 to 2 mm. long and 0.5 mm. wide, which on closer examination proved to be the edges of black metallic tablets. Chemical investigation showed that the magnetite itself was wholly free from titanium and that the tabular inclusions were ilmenite. A study of the orientation of the tabular crystals of ilmenite within the magnetite showed that the basal plane of the ilmenite lay parallel to the octahedral face of the magnetite; that is, the position assumed was that in which similar axes of symmetry lay parallel.

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[a] Cathrein, A., Ueber die mikroskopische Verwachsung von Magneteisen mit Titanit und Rutil: Groth Zeitschr. für Kryst. und Min., vol. 8, 1884, pp. 321–329.

[b] Neef, M., Ueber seltenere krystallinische Diluvialgeschiebe der Mark: Zeitschr. Deutsch. geol. Gesell., vol. 34, 1882, p. 470.

[c] Küch, R., Beitrag zur Petrographie des westafricanischen schiefergebirges: Tschermak's Min. Pet. Mitt., vol. 6, 1885, p. 129.

[d] Teall, J. J. H., On the chemical and microscopic characters of the whin sill: Quar. Jour. Geol. Soc. of London, vol. 40, 1884, p. 657.

[e] Becke, F., Aetzversuche an Mineralen der Magnetitgruppe: Tschermak's Min. Pet. Mitt., vol. 7, 1886, pp. 232–233

In 1892, Rosenbusch[b] stated that Latermann communicated to him the finding of ilmenite intergrowths in the magnetite of the nepheline basalt of the Katzenbuckel, near Heidelberg, Germany. If the magnetite in the thin section were dissolved in hydrochloric acid, there remained a network of ilmenite lamellæ which in sections parallel to the faces of (111) cut each other at an angle of 60° and in sections parallel to the faces of (001) at 90°.

Adams[c] observed two distinct iron ores in the ore particles of the anorthosite of the Morin district, in Canada, on examining thin sections in reflected light. One specimen he describes as having a streaked appearance, due to the fact that one mineral cut the other in a simple or double group of broken laths. On treating the microscope slide with hydrochloric acid the one mineral dissolved, but the laths remained, showing an intergrowth of magnetite with ilmenite, or at least, he says, with a titaniferous iron ore.

In an augite mica diorite from the island of Cabo Frio, Rosenbusch[d] found particles of titaniferous magnetite, which on treatment with hydrochloric acid left behind a network of brownish specular ilmenite.

Lacroix[e] ascribes the titanium content of titaniferous magnetite both to intergrowths of ilmenite and magnetite and to the presence of titanomagnetite. In intergrowths of ilmenite and magnetite the tabular crystals of ilmenite are distributed in the crystals of magnetite parallel to the octahedral face, so that the two minerals have a common ternary axis. The manner of intergrowth is the same as that in the case of hematite and magnetite. He says: "It is very probable that many titaniferous magnetites owe their titanium content to similar groupings of a physical nature and are consequently different from titanomagnetite." Titanomagnetite[a] he calls magnetite in which a small part of the ferric oxide has been replaced by Ti_2O_3.

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[a] Cathrein, A., Verwachsung von Ilmenit mit Magnetit: Groth Zeitschr. für Kryst. und Min., vol. 12, 1887, pp. 40–46.

[b] Rosenbusch, H., Mikroskopische Physiographie der petrographischen wichtigen Minineralien, 1892. p. 287.

[c] Adams, F. D., Ueber das Norian oder Ober-Laurentian von Canada: Neues Jahrb. Min., Geol., Paleon., 1893, B. B. 8, p. 445.

[d] Rosenbusch, H., Mikroskopische Physiographie der massigen Gesteine, 1896, p. 246.

[e] Lacroix, A., Mineralogie de la France et de ces Colonies, vol. 3, 1901–1909, pp. 287–288.

The intergrowths of ilmenite and rutile in magnetite are briefly described by Mügge,[b] who, however, adds nothing to what has been stated above. The chief interest of Mügge's paper is that it discusses at some length the physical and chemical laws governing regular intergrowths of different minerals.

All of the information in regard to the intergrowths of titanium minerals in the magnetite of titaniferous magnetites that had been obtained up to this time came in the course of mineralogical and petrographic studies. No effort had been made to apply the method of attack pointed out by these results to a study of the titaniferous ores themselves. The first investigation of such a character was carried out by Hussak[c] on some Brazilian titaniferous magnetites. Hussak investigated titaniferous magnetite derived both from stringers and veinlets in acidic rocks and from magmatic segregations in basic rocks. Polished plane surfaces of the ores were prepared and etched with hydrochloric acid. The ilmenite, being unaffected by the acid, retained its luster, whereas the magnetite was attacked by the acid, producing a dull-black surface against which the bright ilmenite was easily recognized. He found that the ores consisted in general of aggregates of magnetite and ilmenite, and that the magnetite contained minuter intergrowths of ilmenite, in places regularly intergrown according to the manner already described, and in places irregularly intergrown. The regularly intergrown lamellæ were also found to vary considerably in size and abundance. Five microphotographs of these intergrowths accompanied his article, which so far as known to the author are the only ones that have been published up to the present time.

The lamellar intergrowths of ilmenite were also observed by Warren[d] in the Rhode Island ores, and described as follows:

> On etching the polished surface with hydrochloric acid, a delicate reticulate structure is developed in the ore. With a direct illumination under the microscope, this structure is seen to consist of an intersecting series of bright-gray, narrow bands or lamellæ inclosing dull-black depressions. This structure extends everywhere through the ore except over occasional small areas which have a smooth surface and are iden-

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[a] Lacroix, A., op. cit., vol. 4, 1910, p. 317.

[b] Mügge, O., Die regelmässigen Verwachsungen von Mineralen verschiedener Art: Neues Jahrb. Min., Geol., Paleon., 1903, B. B. 16, pp. 335–475.

[c] Hussak, E., Über die Mikrostructur einiger brasilianischer Titanmagneteisensteine: Neues Jahrb. Min., Geol., Paleon. vol. 1, 1904, pp. 94–113.

[d] Contributions to the geology of Rhode Island. I, Notes on the history and geology of Iron Mine Hill Cumberland by B. L. Johnson. II, The petrography and mineralogy of Iron Mine Hill, Cumberland, by C. H. Warren: Am. Jour. Sci., vol. 25, 1908, pp. 15–16.

tical with the bands in appearance and presumably in composition. The lamellæ are frequently observed to cross at angles of nearly or exactly 60 degrees; again they form a nearly rectangular grating. This structure, taken in connection with the well-known tendency of ilmenite to develop a reticulate structure parallel to the rhombohedral planes, suggests at once that the lamellæ are ilmenite inclosing the more easily dissolved magnetite. The change in direction of the bands in different parts of the ore matrix is the only indication of the existence of individual grains in the ore.

The ratios derived from the rock analysis show conclusively that the two molecules, $R^{II}TiO_3$ and $R^{II}R^{III}_2O_4$, are present, and in about equal proportions. The magnetic susceptibility of particles of the ore, free from olivine and feldspar, was found to be intermediate between that of pure magnetite and ilmenite. It appears, therefore, that the ore matrix consists essentially of an intimate intergrowth of magnetite and ilmenite with an occasional grain of what is probably pure ilmenite. The parallel intergrowth of members of the spinel family with ilmenite has long been familiar to mineralogists, and a similar intergrowth has been suggested by a number of petrographers to explain the composition of the "titaniferous magnetites" of many rocks. Quite recently Hussak has shown by the study of etched surfaces that intergrowths of ilmenite and spinel minerals, particularly magnetite, are very general in the titaniferous ores of Brazil. He also gives a full bibliography of the literature on the subject. It would be extremely interesting to extend the study of titaniferous magnetites still further and ascertain to what extent, if at all, an intergrowth like the one described in the present instance exists in other occurrences. There is still, in spite of the considerable amount of investigation which has been carried on upon "titaniferous magnetites," much uncertainty regarding the exact relations of these two mineral molecules when occurring together.

In order to bring out the relations between the larger ilmenite grains and the magnetite grains of the titaniferous ores of the Adirondacks, Newland[a] prepared polished sections which were etched with acid, and he gives three photographs taken with an ordinary camera. It seems, however, that he did not examine the surfaces under magnification and hence overlooked the ilmenite intergrowths within the dull magnetite areas.

METALLOGRAPHIC METHOD OF INVESTIGATION.

The microstructure of the titaniferous magnetites has been studied in this investigation by the application of what is known as the metallographic method. It is a method that has long been employed in metallurgy for investigating the microstructure of the metals and alloys. Polished surfaces of the substance to be examined are prepared and treated with etching fluids, and the structure brought out in this way is observed with a microscope specially constructed for using reflected light, and known as a metallographic microscope.

The instrument used in this work was the Leitz metallographic microscope in the geological laboratory of the Johns Hopkins University. This instrument is so constructed that the objective is inverted and the illumination, which is provided by a small arc light, is reflected upward from below. The object can therefore be placed face downward on the stage, and the polished surface is at once at right angles to the axis of the microscope. This arrangement has the advantage that it does away with the necessity of mounting the specimens, a detail of considerable importance when a large number of specimens are to be studied.

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[a] Newland, D. H., Geology of the Adirondacks magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, p. 151.

To prepare a polished section, a small piece of ore was chipped or sawed off the hand specimen. The most convenient size was found to be about a half inch square. Elongate pieces were avoided, as it was difficult to keep a plane surface on them in grinding. A little pressure on one side produced a curved surface, and the smallest curvature made the polishing more tedious and necessitated a constant readjustment of the focus of the microscope. The chip was ground down to a plane surface on an ordinary lap wheel, coarse powders being first used, followed by the use of the finest carborundum or emery, until a plane surface had been produced. For the final stages of preparation, a small lap wheel was constructed, run directly by a motor by means of a friction drive. The speed of the wheel could be regulated by changing the gear of the friction drive and by means of a starting box. Duplicate wheels were provided, so that only one kind of powder was used on each wheel. To obtain a smoother surface than was obtained on the large wheel with the finest carborundum, the carborundum was levigated and the finest sediment used on the small wheel. Still better results were obtained when instead of proceeding directly to the polishing stage, the surface was rubbed for a time on a soft whetstone. For this purpose the black stone used in polishing marble was found satisfactory. The final polishing was done with putty powder on a wheel covered with ribless broadcloth.

The polished surface thus prepared was treated with strong hydrochloric acid. The length of treatment necessary to bring out the structure depended greatly on the character of the ore. Coarsely crystallized ore is more quickly acted upon by the acid than fine-grained aggregates. If the etching was not continued long enough, the structure was not well brought out and much detail was lost; on the other hand, if it proceeded too far, the difference in relief became too great and all the details could not be brought into focus at one time. The most satisfactory way was occasionally to remove the specimens from the acid and observe them under the microscope; as soon as the desired contrast was obtained, the etching was stopped.

In preparing the microphotographs accompanying the report a peculiar difficulty was encountered. All the ilmenite intergrowths and the contacts between the larger ilmenite grains and the magnetite showed a blurred effect on one side. Thus, in the case of the linear network, one side of the lines would be perfectly sharp and the other gradually fade away. The author is greatly indebted to Prof. A. H.

Pfund, of the department of physics at the Johns Hopkins University, for the solution of this difficulty. These lines, as well as the other intergrowths, instead of showing on the ground glass as single bright lines showed in the form of spectra; and it was these spectra that were being photographed. Prof. Pfund suggested boring holes in the carbons and filling them with finely pulverized salt and then introducing between the arc and the microscope a filter filled with a solution of potassium bichromate of sufficient strength to cut out all bands of the spectrum beyond the yellow sodium band. In this way what was practically a bright-yellow monochromatic light was produced, as the faint red in this spectrum has no action on the photographic plate. With the aid of this light the blurred effect was eliminated and sharp photographs were produced.

RESULTS OF METALLOGRAPHIC STUDY.

If a polished section of a titaniferous magnetite is treated with hydrochloric acid, the etched surface reveals to the naked eye certain more apparent features of the ore. It is at once seen that the greater part of the section is made up of three principal types of surfaces. Rather light-colored nonmetallic surfaces are at once recognized as the gangue minerals. Dark gangue minerals, which in the unaltered ore can scarcely be distinguished from the ore minerals, magnetite and ilmenite, are bleached and easily recognized. Other parts of the section have remained unaltered and retain their bright metallic surfaces. These consist of grains of ilmenite. Still other areas, made up of grains of magnetite, assume a somewhat dull-black appearance. A closer scrutiny of the magnetite and the ilmenite areas often reveals the presence of minute particles of a nonmetallic mineral that has retained the luster of its polish. These particles are the small spinel crystals so common in the titaniferous ores. Such an etched section is instructive in showing the relations between the grains of magnetite, ilmenite, and gangue minerals. It has the advantage over thin sections of the ores that it brings out more clearly the relations between the ilmenite and the magnetite grains, and the disadvantage that the recognition of the nature of the gangue minerals is more difficult. Photographs of such sections are shown in Plates II, VIII, and IX.

From these plates it is seen that in most cases the relations between the ilmenite and the magnetite grains are those of the constituents of a granular igneous rock. The texture varies from that of a fine-grained rock to that of a coarse-grained rock. As to the relative abundance of the two minerals, in some ores there is little ilmenite and in others the ilmenite greatly preponderates over the magnetite. The relative size of the grains of the two minerals is of the same order of magnitude, though the ilmenite grains average a little smaller than those of magnetite. The most common shape of the grains is roughly equidimensional, but they also assume an elongate and, especially in the case of the ilmenite, even a tabloid shape. The effect produced then is as if most of the elongated ilmenite grains followed the outlines of the magnetite grains, with a few distinctly cutting across. This is well illustrated in Plate II, *D*. The tabular grains more frequently terminate bluntly, but some gradually fray out at the ends, as in Plate XI, *A*.

A close megascopic examination of the magnetite areas of many ores will show that much of the magnetite is not a homogeneous mass, but is intergrown with minute particles of ilmenite in both regular and irregular orientation (Pl. II, *C*, and Pl. VIII, *B*). A microscopic examination of sections of such ores reveals the intergrowths to much better advantage, and discloses many intergrowths that are so minute as not to be visible to the naked eye. The nature of these intergrowths is fully discussed under the descriptions of the individual deposits. The results of the study of the intergrowths are for convenience summarized at this point.

In many of the ores there is a tendency for small granules of ilmenite to arrange themselves within a magnetite grain very close to its contact with an ilmenite grain. The granules are usually elongate and lie either with their longer axes parallel to the outline of the ilmenite grain, or at right angles to it. In most cases they form a discontinuous fringe around the ilmenite grains from which they are separated by a narrow zone of magnetite free from inclusions. This condition is shown at the right end of Plate II, *E*. Sometimes the granules coalesce, forming a continuous rim about the large ilmenite grain; and if the elongate particles are oriented at right angles to the outline of the grain, the rim may attain a width of 0.2 mm., as in Plate VI, *B*. Besides the particles that tend to segregate along the contact with larger ilmenite grains, others of irregular to more or less circular shape are scattered here and there through the magnetite (Pl. IV, Pl. VI, *A*, Pl. XV, *B*, and Pl. XVI, *A*). The more common size of these is a maximum dimension of 0.1 to 0.3 mm.

The magnetite grains are at times separated by a thin film of ilmenite, so that in section the outlines are marked by a bright rim of ilmenite as is seen in Plate IV, *A*. Somewhat analogous to this is the crowding of regular intergrowths along definite lines in the magnetite areas, which are often the periphery of the grains (Pl. XIII, *B*, and Pl. XV, *A*).

The most common forms of intergrowths are those that show in the sections as lines and as dots.

The lines are sections of minute ilmenite lamellæ oriented parallel to the octahedral faces of the magnetite. Hence in a simple magnetite crystal they can be oriented in three different planes, and in a twinned crystal in five different planes. In section, this may give rise to three or to five series of parallel lines; the actual number visible depends of course on the orientation of the section. Plate XV, *A*, illustrates the intergrowths in a simple individual; Plate VI, *A*, the intergrowths in a twinned individual. The angles that the lines make with each other depend also on the orientation of the section. If the section lies parallel to the octahedral face, they intersect at 60°; as the section deviates from this position, the angles approach 0° on the one hand and 90° on the other. But even where the section is so oriented as to expose the three possible directions, intergrowths are not necessarily developed in all three, or at least not equally well developed. Thus, as in Plate III, *B*, the one series of lamellæ is marked by heavy lines, whereas the other two are made up of very small delicate lamellæ. Consequently the pattern produced by the intersecting lamellæ may vary from the equilateral triangular network of a simple magnetite crystal cut parallel to the octahedral face to the more complicated network of five series of intersecting lines in the case of twinned crystals, or to the simplest case of one series of parallel lines, which is most nearly attained in Plate IV, *A* and *B*.

In size the lamellæ range from such as are easily visible with the naked eye (Pl. II, *C*, and Pl. VIII, *B*) to lamellæ so minute as to be scarcely discernible under the highest magnification. The coarsest lamellæ in any of the ores examined occurred in the ores of the Tuscarora mine in Guilford County, N. C. These reach a length of 4 mm. and a thickness of 0.1 mm. They are characterized by local thickenings in the form of protuberances having a thickness as great as 0.2 mm. (Pl. VII, *A*). The distance between the parallel plates averages 0.2 to 0.5 mm., but may be much greater. The plates are distinctly visible to the naked eye and may be peeled off cleavage faces of the magnetite with a knife. Of the other lamellæ examined the only ones approaching the coarseness mentioned were those in the Poplar Lake ore of Minnesota. Aside from these exceptional cases, lamellæ having a length of 1 mm. and a thickness of 0.02 mm. must be regarded as unusually large. Those shown in Plate VI, *A*, and Plate XV, *A*, are among the largest observed.

Generally, instead of one large continuous lamella, there are a number of smaller lamellæ in the same plane, so that in section the effect is that of a broken line instead of a continuous bright line of ilmenite. If unusually thick, they may have a width of 0.02 mm., as in Plate XVI, *A*; but in most cases they are less than 0.005 mm. in thickness, and 0.001 mm. is not at all uncommon. In length every size is represented from lamellæ so minute that their elongation is scarcely discernible to the larger lamellæ mentioned in the preceding paragraph. The delicate short lamellæ showing the broken-line effect are illustrated in Plate IV, *B*, Plate IX, *A*, and in Plate XII, *A*.

As regards the number of lamellæ present, there is also considerable variation. In some ores they are not very numerous and rather widely spaced, as in Plate IV, *A*, Plate XI, *B*, and Plate XVI, *A*. In others they are closely crowded, as in Plate III, *A*, Plate IV, *B*, and Plate VI, *A*. Especially in the case of the more delicate lamellæ the crowding becomes very close, as shown in Plate I, Plate VII, *B*, Plate IX, *A*, and Plate XII, *A*. This crowding becomes in many instances closer and the lamellæ more delicate until the intersecting structure can no longer be discerned, and the magnetite has a peculiar bright luster due to the almost continuous surface of ilmenite. Such grains can easily be distinguished from homogeneous ilmenite grains by the tendency of their luster to show iridescence.

Not only the number but also the distribution of the lamellæ varies greatly. One part of the magnetite surface may be crowded with them so that it shows a closely packed network, and another part, immediately adjacent, may be almost free from intergrowths. Such sudden changes in the distribution of the intergrowths are seen in Plate VII, *B*, and Plate XII, *A*. Then, again, lamellar intergrowths may suddenly terminate and the dots occur in their place as in Plate XI, *B*. Similar to this is the crowding of lamellæ along definite lines in the magnetite, the rest of the area being almost free from lamellæ. These lines are both the outlines between magnetite grains and lines running through the magnetite seemingly with no definite orientation. This effect is illustrated in Plate XIII, *B*, and Plate XV, *A*.

As common as the lamellæ is another variety of intergrowths that show in section as dots with approximately circular outlines. They vary in size from the minutest to the largest, but the impression one receives is that they occur in groups of two sizes—a larger size 0.05 to 0.01 mm. in diameter and a smaller ranging from about 0.002 mm. down to the smallest size observable. Both sizes occur in Plate IV, *B*, and Plate XIII, *A*. Most commonly the dots are irregularly distributed over the megnetite surface, not showing any regular orientation. In some cases, however, they assume a rectilinear orientation parallel to the octahedral cleavages. This is especially prominent with some of the larger dots and is illustrated in Plate XI, *B*, and Plate XIV, *A*. As regards quantity and evenness of distribution the same conditions exist as have been described for the lamellæ. The minute dots may be almost entirely lacking (Pl. XIV, *A*) or they may occur in such numbers as to form almost a continuous surface of ilmenite and produce the peculiar luster on the magnetite that the closely crowded minute lamellæ cause. The uneven distribution of the dots can be seen in Plate XII, *B*, in which there are abundant minute dots at one end and an almost complete absence of them at the other.

One other form of intergrowth has been illustrated in Plate XVI, *B*. This was found in two Canadian ores, the one illustrated from the River Chaloupe and another from a deposit 40 miles north of Montreal. No such intergrowth was observed in any of the ores from the United States. It consists of numerous narrow lenticular bands of what seems to be magnetite, though it is not as readily acted on by the acid as magnetite usually is, intercalated in grains of ilmenite. Hussak[a] found what is probably the same kind of intergrowths in the Brazilian ores from Victoria in Espirito Santo and Caldas in Minas Geraes, the former occurring in a quartz mica diorite, the latter in a basic rock. Of the Victoria ore he says: "The large ilmenite grains show a peculiar lamellation after etching and appear to consist of two substances acted on unequally by the acid, although both are very difficultly soluble in 50 per cent hydrochloric acid." The structure would suggest the solidification of a magnetite-ilmenite eutectic and is worthy of further investigation.

It is at once apparent from the microphotographs that all of the intergrowths that have been described are too minute to admit of a mechanical separation. In many cases they are abundant enough to give the magnetite a considerable titanium content, and herein lies the failure to a large extent of magnetic separation to eliminate the titanium from the ores. But it has also been demonstrated that a magnetite showing none of the intergrowths, but etching with a uniform dull-black surface, may carry a large percentage of titanium. A sample obtained by picking particles of etched magnetite free from intergrowths from sections of Sanford Hill ore contained 6.6 per cent Ti. It would appear, therefore, that the magnetite molecule may itself carry titanium and establish the existence of a mineral "titanomagnetite." The titanium content of titaniferous magnetites that is inseparable by means of magnetic concentration, consequently, occurs both in the form of microscopic inclusions of ilmenite and in the magnetite molecule itself. The quantity of titanium occurring in separable and inseparable form is subject to variation between wide limits. Hence it is impossible to predict beforehand what results the magnetic separation of a given titaniferous ore will yield, but each case must be investigated for itself.

CHEMICAL COMPOSITION OF THE TITANIFEROUS IRON ORES.

In the section of this report dealing with the individual deposits of titaniferous iron ores all the available analyses of titaniferous iron ores have been included. At this point some of the characteristic features of the chemical composition of these ores are discussed. The table following gives the average content of the ores, by districts, in iron, titanium, phosphorus, and sulphur. The figure in parentheses indicates the number of determinations from which the average is made up. The last column gives the amount of titanium per unit of iron.

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[a] Hussak, E., Über die Mikrostructur einiger brasilianischer Titanmagneteisensteine: Neues. Jahrb. Min., Geol., Paleon., vol. 1, 1904, pp. 99, 108.

Average composition of titaniferous magnetites.

Source of ore.	Fe.	Ti.	P.	S.	Titanium per unit of iron.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Iron Mine Hill, R. I.	33.49 (10)	5.85 (10)	0.016 (5)	0.104 (5)	0.1747
New York gabbro ores	44.66 (21)	6.28 (21)	.117 (16)	.237 (11)	.1406
New York anorthosite ores	57.21 (15)	9.61 (15)	.015 (6)	.035 (6)	.1680
New Jersey	57.83 (40)	1.90 (40)	.289 (40)	.3657 (34)	.0329
North Carolina	49.98 (58)	6.61 (56)	.023 (36)	.052 (29)	.1323
Minnesota	49.11 (11)	7.94 (11)	.006 (7)	.126 (7)	.1617
Iron Mountain, Wyo	49.89 (10)	15.96 (10)	Trace.(1)	.87 (3)	.3199
Caribou Hill, Colo	45.57 (4)	12.37 (2)	.020 (2)	....	.2715
Iron Mountain, Colo	47.86 (11)	7.68 (10)	.026 (8)	Trace. (1)	.1605
Cebolla Creek, Colo	....	13.61 (2)	....	....	....

One of the most interesting things brought out by this table is the relation existing between iron and titanium. Attempt is made subsequently to show that most if not all of the ores from which the New Jersey averages have been calculated really do not belong to the class of ores under discussion, and hence the New Jersey figures may be ignored. The average titanium content given for the Caribou Hill deposit is beyond doubt wrong. The divergence between Jennings's analysis and Chauvenet's is so great, and the metallographic study of the ore so greatly favors Jennings's determination, that the average of the two certainly does not represent the actual titanium content, but is a figure far above the true value. Hence this average must also be ignored. We then find that the ratio of titanium to iron in the magnetites of all the districts mentioned ranges between the narrow limits of 0.1323 and 0.1747, with the single exception of the magnetite from Iron Mountain, Wyo., which has a ratio twice as great as the average of the others.

The phosphorus content is unusually far below the Bessemer limit. In a few cases, however, the ore contains considerable apatite, which gives it a high phosphorus content. Assumption can not be made, therefore, that a given deposit is low in phosphorus, but it should be tested in this respect. The chances of its exceeding the Bessemer limit are, however, very slight. The sulphur content is also very low, and in no case high enough to produce any deleterious effects.

The geology, origin, and composition of the titaniferous iron ores have been discussed at considerable length by Vogt in a series of articles that appeared in the "Zeitschrift für praktische Geologie" during the years 1893, 1894, 1900, 1901, and 1910. A brief summary of these results is given in "Die Lagerstätten der nutzbaren Mineralien und Gesteine,"[a] by Beyschlag, Krusch, and Vogt.

Vogt finds that the iron-ore segregations occurring in gabbros, labradorfels, and augite and nepheline syenites are characterized all over the world, without exception, by a considerable titanium content. The titanium in the relatively rich segregations rarely falls below 4 to 5 per cent. Another element that is rarely lacking is vanadium in the form of V_2O_3, and there may also be present Cr_2O_3, NiO, and CoO. The manganese content is usually low. The apatite or P_2O_5 content is generally low. The quantity of sulphide is usually small, and in a few cases carbon in the form of graphite occurs. A review of the analyses of the titaniferous ores of the United States showed that they conform in every respect to the characteristics outlined by Vogt.

As regards their manner of occurrence, Vogt states that they occur in the central parts of the eruptive masses into which they gradate as irregular schlieren, or as distinct dikes with sharp contacts against adjacent eruptive rock. All these types of occurrences are represented among the deposits of the United States. The manner in which the differentiation progresses is discussed by Vogt and is illustrated graphically by diagrams, and the theory of the processes of differentiation is considered. A consideration of these points is, however, beyond the scope of this report.

Of more immediate interest is Vogt's discussion of the relations of the iron, titanium, phosphorus, and sulphur of the ores to the original content of these elements in the magma. Omitting certain analyses that he regarded as unreliable, the analytical results collected by him covering occurrences all over the world showed that the ratio between titanium and iron ranges between 0.063 and 1. Only in rare cases, however, does the ratio fall without the limits 0.1 and 0.667; and in the vast majority of cases of segregations within gabbros and anorthosites relatively rich in iron-magnesian silicates the ratio lies between 0.111 and 0.250. The table on page 35 shows that all of the American occurrences, ruling out those of New Jersey and Caribou Hill for reasons already stated, fall within this narrow limit with the exception of the Iron Mountain, Wyo., deposit. This deposit occurs in anorthosite relatively poor in ferromagnesian minerals, and such deposits Vogt states are characterized by a higher titanium content. A thoroughly trustworthy ratio of titanium to iron in the original gabbroitic magma can not be given, but he regards it as falling below 0.1 to 0.125. Hence in the processes of differentiation not only has there been an absolute enrichment of iron and titanium, but titanium has to a varying extent been enriched relatively to the iron.

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[a] Vol. 1, 1909, pp. 247-253.

According to Clarke,[a] the eruptive rocks carry an average of 0.11 per cent of phosphorus and 0.11 per cent of sulphur; but the gabbroitic rocks carry more than the average quantity of these two elements, and Vogt assumes as the minimum an average of 0.2 per cent of phosphorus and 0.15 per cent of sulphur for these rocks. The average phosphorus content of the titaniferous iron ores is far below this figure, and in only a few cases does it reach that quantity in individual deposits. The high-grade ores usually carry only the minutest quantity of phosphorus. The sulphur content is also usually very minute. In a few cases there is a considerable sulphur content in the ores owing to the presence of sulphides, but in most cases the average is below the average for the magma. Consequently, the assumption is warranted that while the iron and titanium were being enriched to form the ore bodies the phosphorus and sulphur remained in the magma. In other cases there have been segregations of apatite and of sulphidic ores. Vogt concludes, therefore, that the conditions favorable to the segregation of iron and titanium differ from those favorable to the segregation of phosphorus, and these again from those favorable to the segregation of sulphides; and that in most cases these conditions do not exist at the same time or place.

He also takes up the behavior of some of the less essential constituents of the ores in this respect. A slight enrichment of manganese has taken place, but not to the extent to which iron has been enriched. Kemp found that chromium and vanadium vary in the same manner if not absolutely in the same degree. This relation is corroborated and the average enrichment of these two elements in the ores given as tenfold. The nickel and cobalt content is usually small and in most cases less than one would expect.

In conclusion, it may be stated that the characteristics of the chemical composition of the titaniferous iron ores of the United States are the same as those that mark these ores the world over. As regards iron content most of them must be classed as medium to low grade ores. Fortunately, however, the deposits with the greatest economic possibilities are the richest and their ores are high grade. Phosphorus and sulphur are present in objectionable quantities in only rare instances; and phosphorus especially is unusually low in the most promising deposits. The slag forming compounds, lime, magnesia, alumina, and silica, are present almost entirely in the gangue minerals, and play no important rôle in the composition of the ores. The high-grade ores in which the iron content is high enough for direct furnace use contain little gangue. The lower-grade ores would have to be subjected to magnetic concentration to bring their iron content within the required limits, and this would reduce the percentage of those constituents in the concentrates to a minimum.

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[a] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911.

ECONOMIC IMPORTANCE OF THE DEPOSITS.

The field investigation of the titaniferous iron ores has given the author the impression that the possibilities of these ores with reference to the iron-ore resources of the country have been grossly exaggerated in many quarters. In the detailed description of the more important deposits of these ores that follows, their commercial aspect is discussed so far as available data make this possible, and the statements made here are in the nature of conclusions based on those discussions.

Least promising are the possibilities of the ores in the ferromagnesian rich rocks. As a general rule, the deposits are of small and irregular extent, and the ores fine grained and lean. Leaving out of consideration for the moment their titanium content, they are ores that would require magnetic concentration before they could be used in the blast furnace. Further, most of the deposits are inaccessible to adequate transportation facilities. Their situation both topographically and with regard to the industrial development of the country at large is such that there are no prospects of transportation facilities being provided for a long time to come. Hence, to put these deposits on a producing basis, the heavy initial expense would have to be incurred of erecting magnetic concentrators and providing adequate transportation facilities. The small extent of most of the deposits and their irregular distribution make those costs prohibitive. Then, their titaniferous character must be taken into consideration. The relations of ilmenite and magnetite in the ores are such that the least favorable results would be obtained in the elimination of titanium by magnetic concentration. In fact, the titanium would be increased together with the iron; so that the higher the iron content of the concentrates, the higher would be their titanium content.

In the case of the ores in the anorthosites and the feldspar-rich gabbros, the conditions are much more favorable. As a general rule the ores are much coarser grained and richer. This tendency to coarser-grained, rich ores is noticed where the gabbros assume an anorthositic facies. Thus in some of the feldspathic phases of the Duluth gabbro, in Minnesota, the ores are coarser grained than the normal gabbro ores, and small segregations of comparatively pure ore occur. Also at Iron Mountain, Colo., the immediate country rock shows an anorthosite phase, and the ores are richer and coarser grained than ordinary gabbro ores and greatly resemble the typical ores in anorthosite.

Two deposits in anorthosite stand out above all other titaniferous iron-ore deposits in the United States; these are at Sanford Hill, N. Y., and Iron Mountain, Wyo. At each of these localities, in addition to the one enormous deposit, there are smaller but important deposits with the same kind of ore. At neither place has a careful estimate of available tonnage been made, but it is apparent from the known extent of the deposits that the quantity of ore that can be mined by simple quarrying methods alone runs into millions of tons. The ores are nearly pure aggregates of magnetite and ilmenite, the gangue minerals being so subordinate in amount as to be negligible. The average composition of the Adirondack ore corresponds to 62.8 per cent magnetite and 30 per cent ilmenite, whereas that of the Wyoming ore is equivalent to 49.8 per cent magnetite and 40.15 per cent ilmenite. The results of magnetic concentration tests show that the Adirondack ore would yield a concentrate containing less than 7 per cent Ti and the Wyoming ore a little less than 10 per cent. The titanium content of the Adirondack concentrate is low enough to make feasible its mixture with several parts of nontitaniferous ore to make a product low enough in titanium to be used in ordinary blast-furnace practice. The low phosphorus and sulphur content of the concentrate would make it a desirable material for mixing with ores of non-Bessemer grade and high in sulphur. The concentrates of the Wyoming ore are rather high in titanium for this purpose, and it is probable that these deposits will have to await some such process as electrical smelting that will make possible the direct smelting of titaniferous ores. To provide adequate transportation facilities for the Sanford deposit will require the construction of more than 30 miles of railroad over a mountainous country; for the Iron Mountain deposit, only 10 miles will be necessary, and the construction will be much easier. In both cases the deposits are large enough to warrant this expense.

To sum up, it may be confidently asserted that the Lake Sanford and Iron Mountain, Wyo., deposits are important ore bodies that before many years will be furnishing a considerable tonnage of iron ore. The rest of the titaniferous iron-ore deposits of the United States can not for many years to come be of any value as sources of iron ore.

CHARACTER, SITUATION, AND POSSIBILITIES OF THE DEPOSITS.

In the subsequent pages the more important deposits of titaniferous iron ores in the United States are described individually. The order of treatment is geographic, beginning in the northeast with Rhode Island and continuing southward and westward. The method pursued has been to give first a summary of the geologic features of a given deposit in order to prepare the way for an adequate discussion of the metallographic features of its ores and of its economic possibilities.

RHODE ISLAND

IRON MINE HILL DEPOSIT.

The titaniferous magnetic iron ore of Iron Mine Hill, R. I., has been known for over two centuries, and has been of such interest to geologists that repeated mention of the deposit is made in geological literature. The most recent and thorough study of this deposit is that by Johnson and Warren,[a] who made a careful study of the deposit itself, and included in the presentation of their results a historical account of the deposit and a summary bibliography of the pertinent literature. In view of this thorough study and careful description of the deposit, the author of this report has not deemed it necessary to revisit the locality. The following description of the deposit being based chiefly on the paper by Johnson and Warren.

LOCATION.

Iron Mine Hill lies in the northeast corner of Rhode Island, near the Massachusetts line, in the town of Cumberland, about 3 miles east of Woonsocket. The region is heavily drift covered and of moderate relief, the hills not rising much more than 100 feet above the surrounding country. One of these hills consists of a heavy rock which early attracted attention as a possible source of iron ore, and it has since received the name Iron Mine Hill. The dimensions of the hill as given by Jackson[b] are 462 feet long, 132 feet broad, and 104 feet high. The area occupied by the ore body is even larger. The exact boundaries are covered, but it appears from surface indications and magnetic observations that the ore body has a length of 1,200 feet and a width of 500 to 600 feet. The direction of the longer dimension is nearly north and south.

HISTORY.

Repeated attempts have been made to utilize this ore. As early as 1703 it was mixed with hematite from Cranston, R. I., and used in a foundry probably located in the town of Cumberland. Part of the cannon used against Louisburg in 1745 were made at this forge, and the ores were utilized for this purpose during the Revolutionary War. Attempts were made to use the ores during the early and middle parts of the last century by mixing them with high-grade ores at furnaces in New York, Pennsylvania, and New England. In all several thousand tons of ore have been used. The great drawback has always been their low iron content and the high percentage of titanium that they carry. The enormous quantity of the ore and the low phosphorus and sulphur content have been advantages that have partly offset the disadvantages. However, no attempt to work the ores for their iron has been made for many years, and an attempt to use the rock for road metal (macadam) at the close of the last century also met with failure, probably because its extreme toughness made its quarrying too expensive.

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[a] Contributions to the geology of Rhode Island. I, Notes on the history and geology of Iron Mine Hill, Cumberland, by B. L. Johnson. II, The petrography and mineralogy of Iron Mine Hill, Cumberland, by C. H. Warren: Am. Jour. Sci., 4th ser., vol. 25, January, 1908, pp. 1-38.

[b] Jackson, C. T., Report on the geological and agricultural survey of the State of Rhode Island, 1840, p. 52.

ORIGIN.

Jackson[a] was the first to recognize the eruptive character of the ore. The first microscopic study of the ore was made in 1881 by Wadsworth,[b] who called attention to its similarity to the celebrated iron ore of Taberg, Sweden. Though the origin of the rock could not be told from its field relation, he considered that its mineral association and microscopic characters indicated that it was an eruptive rock. He therefore concluded that the deposit was of eruptive origin. In 1884, Wadsworth[c] proposed the name cumberlandite for this and similar rocks.

Opposed to the eruptive theory at this time were men like Hitchcock[d] and Dana,[e] who considered the magnetite to be of metamorphic origin.

At present the igneous origin of the cumberlandite is not doubted, the general opinion being it is probably a segregation from a gabbroitic magma.

GENERAL FIELD RELATIONS.

Unaltered cumberlandite is exposed at only one point on the western slope of the hill. This area of fresh rock, about 300 to 400 square feet, passes over, with a comparatively narrow transition zone, into the altered types that form the greater part of the hill. One of the first changes in the rock consists in the alteration of the feldspar phenocrysts to dark-green chloritic aggregates, in association with which a little actinolite may occur. Such rock makes up the greater part of the exposures. As alteration progresses the olivine also passes into chlorite and actinolite, and in the final stage olivine and actinolite are changed to serpentine. The analysis cited below, from Wadsworth, was probably that of a sample of ore in which the feldspar had undergone changes.

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[a] Op. cit., p. 53.

[b] Wadsworth, M. E., A microscopic study of the iron ore, or peridotite, of Iron Mine Hill, Cumberland, R. I.: Mus. Comp. Zool. Harvard College Bull. 7, 1881, pp. 183-187.

[c] Wadsworth, M. E., Lithological studies: Mem. Mus. Comp. Zool. Harvard College, vol. 11, 1884 p. 80.

[d] Hitchcock, Edward, Final report on the geology of Massachusetts, 1841, p. 554.

[e] Dana, J. D., Iron ore of Iron Mine Hill, Cumberland, R. I.: Am. Jour. Sci., 3d ser., vol. 22, 1881, p. 152.

The rock is cut by a major system of joints that is parallel to the long direction of the hill and has a nearly vertical dip. A minor series of joints, approximately at right angles to these, cuts the hill into small, rudely prismatic blocks. Many of these blocks have been plucked out by the ice, leaving an irregular broken surface. Shearing movements which have produced a schistose structure in the secondary actinolite and chlorite formed along the joint planes.

The cumberlandite is nowhere exposed in contact with any other rock, and is separated from the nearest outcrops by barren areas for a distance of at least 700 feet. The surrounding rocks consist of green chlorite-epidote schist and quartzose biotite schist cut by numerous quartz veins and granite dikes, granite, diabase, and a coarse-grained metamorphosed gabbro. The gabbro extends in a series of heavily glaciated ridges around the west side of the hill for a distance of three-quarters of a mile, obtaining a width of one-quarter of a mile. It is everywhere separated from the cumberlandite by swamps and drift, so that no contact can be observed.

The occurrence of inclusions of gabbro in the cumberlandite at several places indicates a not distant contact. Moreover, a line connecting the known northeastern and southeastern limits of the gabbro would pass close to the supposed western limit of the cumberlandite. The evidence, therefore, indicates the intrusion of the cumberlandite into the gabbro. The basic character of both, their titanium content, and their occurrence as adjoining masses surrounded by genetically unrelated rocks suggested to Johnson that they are offshoots from a common magma. Such a differentiation within the magma and subsequent intrusion of the one differentiate into the other instead of differentiation in situ has, according to the observations of the author, very frequently occurred in the case of the titaniferous magnetites. Though this deposit has many features in common with the well-known Taberg deposit in Sweden, resemblances that are just as strikingly brought out in the metallographic study of the two ores, this is one essential difference in the two deposits. The Taberg ore is an example of differentiation in situ. The ore, a magnetite olivenite, has segregated in the center of a mass of *olivine* hyperite. Here there is a transition from country rock to ore; at Iron Mine Hill, the ore was intruded into the gabbro, and if exposed the contact would be sharp and not gradational.

The gabbro is not cut by the surrounding granite, and no inclusions of the granite or sedimentaries in the gabbro are known. Positive evidence of the relative ages of the gabbro and the surrounding rocks is lacking. Johnson[a] suggests that the gabbro is younger than the schists but older than the granite, since such a sequence has been determined in the case of a mass of gabbro surrounded by schist and granite at Norwich, Conn., about 80 miles southwest of Cumberland.

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[a] Johnson, B. L., and Warren, C. H., Contributions to the geology of Rhode Island: Am. Jour. Sci., 4th ser., vol. 25, January, 1908, pp. 10-11.

The gabbro was originally a rather coarse-grained rock, consisting of labradorite, averaging about Ab_1An_1, a purplish augite of distinctly diabasic habit, an unusual proportion of ilmenite in the form of large grains closely associated with the augite, and accessory apatite. Shearing and metamorphism have affected the gabbro mass unevenly. The central and southern parts are least affected; the northern parts have been more severely altered, and in part changed into fissile green schists.

CUMBERLANDITE.

The cumberlandite has a characteristic appearance and can be readily distinguished macroscopically from all other known titaniferous magnetites in the United States. In a grayish-black, fine-grained groundmass of irregular fracture are embedded relatively large tabular crystals of plagioclase. Two constituents of the groundmass can be recognized with the eye alone. One is a yellowish glassy olivine, the other a grayish-black mass of magnetite and ilmenite.

Plagioclase makes up about 13 per cent of the rock. The crystals average 1 cm. square by 2 mm. thick and range in size from minute grains to a maximum of 2 cm. square by 2 to 3 mm. thick. The common segregation of two or more feldspar crystals gives the rock a cumulophyric texture. Locally a tendency to parallel or fluidal arrangement is noticeable, but there is no persistent direction of orientation maintained. Though the feldspar is more abundant in one place than in another, it has a fairly uniform distribution throughout the rock.

At the contacts between the feldspar and the groundmass reaction rims are always developed; but they are exceedingly narrow, ranging from 0.003 to 0.01 mm. At the feldspar-olivine contacts, the reaction rim consists of pale-green to colorless needles of actinolite that are perpendicular to the contact. At many ilmenite-magnetite-feldspar contacts shreds of biotite appear; and in some places they occur as a narrow border next to the magnetite, with a border of actinolite on the feldspar side.

The texture of the groundmass is well shown on a polished surface of the ore, especially after etching with strong hydrochloric acid, which causes the dark glassy olivine to lose its high luster and to stand out as a light-yellow lusterless substance in a network of magnetite and ilmenite. The olivine occupies somewhat more than half of the surface.

In thin sections the olivine is seen to consist of a mosaic of anhedral grains ranging in size from minute particles to individuals 5 mm. long by 2.5 mm. wide. In general the olivine lacks crystallographic outlines, yet throughout the rock the magnetite-ilmenite acts as the matrix. The following analysis, made by Warren, shows it to be a hyalosiderite:

Results of an analysis of olivine from cumberlandite.

	Per cent.
SiO_2	37.16
TiO_2	.07
Fe_2O_3	.12
FeO	31.38
MnO	.40
CaO	Trace.
MgO	31.16
Feldspar (insoluble)	.34
	100.63
Fe	24.5

Spinel occurs at random in the ore in the form of minute subangular grains, reaching a maximum size of 0.45 mm. by 0.12 mm. More commonly they are equidimensional grains averaging 0.10 to 0.20 mm. in diameter. The spinel is seen in thin sections as a dark-green, feebly transparent isotropic mineral, which was called glass by Wadsworth, but thought to be hercynite by G. H. Williams. Warren calls it pleonaste.

CHEMICAL COMPOSITION OF ORE.

The results of a number of analyses of cumberlandite are available, but the only complete one is that made by Warren. The available results are presented below:

Results of analyses of Iron Mine Hill ore.

Constituent.	1[a]	2[b]	3[c]	4[d]	5[e]	6[f]	7[g]	8[h]	9[i]	10[j]
SiO_2	22.35	23.00	22.87	20.85	20.85	20.77	26.33			20.41
Al_2O_3	5.26	13.10	10.64	5.55	5.26	4.01				
Fe_2O_3	14.05	27.60	44.88	45.62	16.32	17.22	58.50			
FeO	28.84	12.40			28.53	26.51				
TiO_2[k]	10.11	15.30	9.99	9.98	9.63	10.08	3.66	9.35	9.86	11.75
MnO	.43	2.00	2.05				2.10			.05
CaO	1.17		.65	.73	.98	.53	.65			
MgO	16.10	4.00	5.67	16.45	17.60	17.96	6.80			
Zn	.71		.20							
H_2O	.42	2.60	3.05		.66	2.70	1.96			
P_2O_5	.02			Trace.				.026	.026	.103
S	.38			Trace.				.057	.057	.023
V_2O_3	.18									None.
Cr_2O_3	Trace.									
Na_2O	.44									
K_2O	.10									
CO_2	.02									
Cu	.08									
Co-Ni	.08									
Pb	Trace.									
Total	100.74	100.00	100.00	99.13	99.83	99.78	100.00			
Fe[l]	32.5	28.96	32.49	33.03	33.67	32.73	42.35	32.80	32.84	33.87

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[a] Warren, C. H., Contributions to the geology of Rhode Island. The petrography and mineralogy of Iron Mine Hill, Cumberland: Am. Jour. Sci., 4th ser., vol. 25, January, 1908, p. 24.

[b] Jackson, C. T., Geol. Survey of R. I., op. cit., p. 53.

[c] Thurston, R. H., quoted by Wadsworth: Mus. Comp. Zool. Harvard College Bull. 7, 1881, p. 185.

[d] Drown, T. M., quoted by Wadsworth: pp. 16–17.

[e] Packard, R. L., quoted by Wadsworth, M. E.: Mem. Mus. Comp. Zool. Harvard College, vol. 11, pt. 1, 1884, Report of the State Board (of Michigan) Geol. Survey for the years 1891–92, Lansing, 1893, p. 95 (ore with feldspar).

[f] Same as foregoing (ore without feldspar).

[g] Chilton, —, quoted by Holley, A. L.: Trans. Am. Inst. Min. Eng., vol. 6, 1878, p. 226.

[h] Tenth Census U. S., vol. 15, 1886, p. 567.

[i] Same as foregoing, but dried.

[j] Data furnished by W. L. Cumings, of the Bethlehem Steel Co.

[k] Average, 9.75.

[l] Average, 33.49.

Calculating its position in the quantitative classification, Warren found that the ore fell in an order and rank for which there was no name, and at the suggestion of Prof. L. V. Pirsson he proposed the names rhodare and rhodose from the State in which the rock occurs. The stem cumberland was rejected in order to prevent confusion with the better known town of Cumberland in England. The mode as calculated by Warren is given below.

Mode of cumberlandite.

Mineral.	Percentage by weight.	Percentage by volume.
Orthoclase	0.56	0.8
Labradorite (Ab_6An_4)	9.23	13.7
Olivine	46.08	49.4
Magnetite	20.65	15.9
Ilmenite	18.63	15.2
Spinel	3.55	3.9
Sulphides	1.15	1.1

Because the name cumberlandite is widely known its use in this discussion has been deemed advisable.

METALLOGRAPHIC DESCRIPTION OF THE ORE.

As already stated, the ore minerals form the matrix for the olivine and the other minerals of the groundmass. They occur in irregular areas of about the same size as the olivine grains or a little smaller, and except in the altered phases are more or less connected with each other. They form a little less than 50 per cent of the groundmass.

When a polished surface of the ore is etched with hydrochloric acid a part of the ore remains bright, whereas the greater part shows a dull-black background on which a delicate reticulate structure has been developed. The bright grains, which are ilmenite, are usually quite small, rarely having a maximum dimension of 2 mm., and form only a small percentage of the ore. The reticulated structure of the ilmenite growth in the magnetite is especially characteristic in this ore. It is marked by the minuteness of the lines and the closeness with which they are crowded. They range in fineness from such as are shown in Plate I, *A*, down to such minute intergrowths as not to be resolvable by the magnification used in the figure. Such areas are distinguishable under the metallographic microscope from areas of true ilmenite by their peculiar iridescent luster. The coarsest of the lines attain a length of only 0.15 mm. The same delicate minute network is also characteristic of the Taberg ore with which the Iron Mine Hill ore has so often been compared geologically. The similarity of the structure is brought out in Plate I, *A* and *B*.

The metallographic features of this ore distinguish it from all the other American ores that were studied, as is at once apparent from a comparison of the microphotographs shown in this report.

POSSIBILITIES OF UTILIZATION.

The size of the deposit and its low phosphorus and sulphur content would indicate the desirability of working it. However, more than offsetting these advantages are its low iron content and its titaniferous character. The low percentage of iron could be overcome by magnetic separation were not the character of the ore such as to make magnetic concentration impracticable. The magnetite and the ilmenite are so intimately intergrown that with the exception of the larger grains of ilmenite the ilmenite would be concentrated equally with the magnetite.

The result of a perfect separation of the ilmenite and the magnetite from the gangue minerals can be calculated from the mode of the rock given above. About one-third of the iron of cumberlandite is contained in the olivine, and this would go into the tailings, leaving only two-thirds or about 22 per cent Fe for the concentrates. Again, assuming that one-third of the titanium could be removed by the separation of the larger grains of ilmenite, a percentage greater than is actually the case, the iron would be still further decreased by more than 2 per cent and the titanium by nearly 2 per cent. Such a perfect concentrate would contain, therefore, 20 per cent of cumberlandite in the form of iron and 4 per cent in the form of titanium, in a bulk one-third by weight of the original rock. In other words, it would take 3 tons of ore to produce 1 ton of concentrates analyzing 60 per cent Fe and 12 per cent Ti.

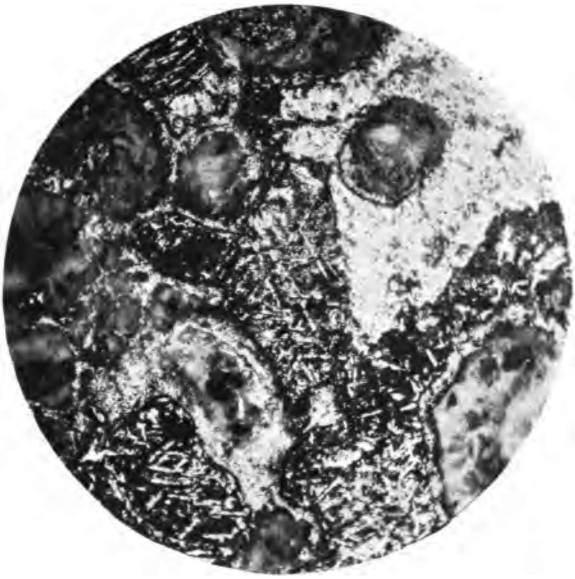
A concentration made on a commercial basis would show results still less favorable. The percentage of iron would fall below 60 per cent without a corresponding decrease in titanium, as, with a less complete separation, a smaller percentage of ilmenite than that assumed above would be removed. Consequently the cost of obtaining the degree of concentration necessary to produce a product high in iron would be excessive, even if the resulting product would not be unsalable on account of its high titanium content.

NEW YORK.

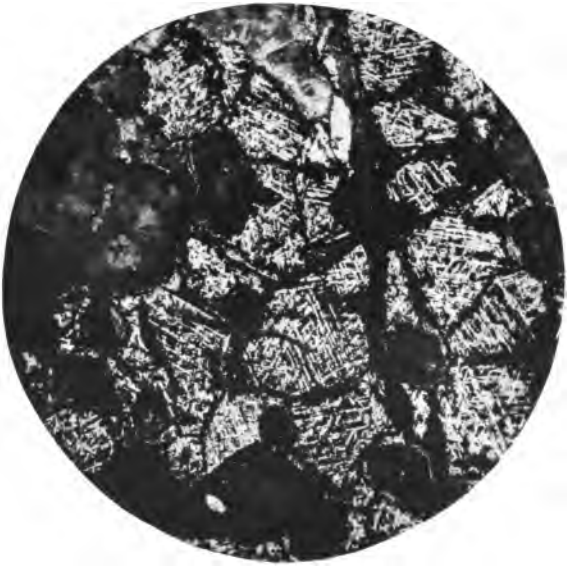
Titaniferous iron ores occur in New York State in the Adirondack Mountains and on the east bank of the Hudson River below Peekskill.

DEPOSITS IN THE PEEKSKILL REGION.

At this locality there is an area of about 25 square miles that consists of rocks of the gabbro family known as the Cortlandt series. Associated with these rocks are highly aluminous titaniferous ores



A. IRON MINE HILL, R. I., ORE. (X 60.)



B. TABERG, SWEDEN, ORE. (X 60.)

which have attracted considerable attention both as a source of iron and as a source of emery. These ores differ from normal titaniferous magnetites in their low titanium content and in the high percentage of alumina that they carry. The percentage of TiO_2 ranges from 0.15 to 4.15 per cent, and that of alumina from 20 to nearly 50 per cent. Mineralogically they consist of spinel, magnetite, and corundum. The percentage of iron ranges from about 30 to 40 per cent, but averages about 33 per cent. The deposits do not seem to be of any importance from the standpoint of iron ores, and their titanium content is so low as not to seriously interfere with their use in ordinary blast-furnace practice, especially if mixed with nontitaniferous ores. Hence no special study of them was made in connection with this report. They have been described by Dana [a] and by Williams.[b]

DEPOSITS IN THE ADIRONDACK REGION.

The titaniferous magnetites of the Adirondack region belong to the normal type. The ores have been studied in considerable detail by Kemp, and in his papers are more fully described than any other deposits of titaniferous ores in the United States. The most complete account is that on "The Titaniferous Iron Ores of the Adirondacks."[c] More recently Newland [d] published an account of these ores, which, however, he says is based chiefly on the descriptions and conclusions of Kemp. The deposits in the gabbros in the townships of Elizabethtown and Westport were again described in 1910 by Kemp, some additions being made to the earlier descriptions.[e] These articles refer to previous contributions and include the information available at the time they were written. The following descriptions of the occurrences are based chiefly on Kemp's accounts, and are supplemented by additional information taken from Newland's bulletin and observations made by the author at those deposits visited by him.

DISTRIBUTION OF THE ORE DEPOSITS.

The titaniferous ores of the Adirondacks are associated in all but one doubtful case with rocks of the gabbro family. Consequently their distribution is determined by that of the gabbro rocks. The principal area of these rocks is in Essex and southern Franklin Counties, where they occupy about 1,200 square miles. Smaller outlying intrusions are found in Clinton and Warren Counties and in the western Adirondacks. Most of the deposits occur in the townships of Westport, Elizabethtown, and Newcomb, in Essex County.

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[a] Dana, G. D., Geological relations of the limestone belts of Westchester County, N. Y.: Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 199-200.

[b] Williams, G. H., The norites of the "Cortlandt series" on the Hudson River near Peekskill, N. Y.: Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 194-199.

[c] Kemp, J. F., 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 377-422.

[d] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, pp. 146-170.

[e] Kemp, J. F., and Ruedemann, R., Geology of the Elizabethtown and Port Henry quadrangles: N. Y. State Mus. Bull. 138, 1910, pp. 137-149.

FIELD RELATIONS OF THE ORES.

The principal geological features of the deposits are concisely stated by Kemp [a] and his account is quoted nearly in full in the paragraphs following:

> The titaniferous ores of the Adirondacks are associated in all cases [b] with rocks of the gabbro family and with two well-marked varieties belonging to it. The two are contrasted in appearance and are easily recognized. The largest ore bodies are contained in rocks that are chiefly labradorite, in the coarsely crystalline granitoid aggregates that have been called anorthosite by the Canadian geologists, within whose territories they are abundant. A little augite or hypersthene is always present in a very subordinate capacity, and rims of garnet are common around the bisilicates. The ores in anorthosites are limited to Newcomb, Wilmington, and North Hudson townships, and lie among the highest peaks of the mountains. In their geological associations and general character they are practically like the huge masses of ore that occur along the lower St. Lawrence in Quebec and near Ekersund in southwestern Norway.
>
> The smaller ore bodies, although still of very considerable size, are found in a dark basic gabbro or norite, in which the ferromagnesian silicates predominate over the feldspar. Labradorite is the feldspar and green augite the chief bisilicate. Hypersthene is sometimes abundant and olivine is frequently present. Small garnets in granular rims about the bisilicates are quite invariably present, and shreds of biotite are by no means uncommon. Brown hornblende is an important constituent in and near the ore, and is also common throughout the mass of the rock. Small, irregular anhedra of titaniferous magnetite are always disseminated in the gabbro, and apatite is, of course, not lacking. In texture the rock approximates the diabasic granular type, because of the marked tendency of the feldspar to form lath-shaped individuals.
>
> The ores in the gabbro are contrasted in physical appearance with those in the anorthosite. The former are closely crystalline and dark gray, with a dense, compact aspect, like a finely crystalline igneous rock. The titaniferous magnetite is in relatively small individuals and is mingled with ferromagnesian silicates. The ore from the anorthosites is coarsely crystalline, like ordinary magnetites. It sometimes has a bluish shade, which is regarded by many as characteristic. It lacks the abundant ferromagnesian silicates, and contains large feldspars instead. The greater coarseness of crystallization is in great part due to the larger masses in which it occurs. The contrasts in the grain of the ores, however, are fully reproduced in the textures of the wall rocks, and the ores vary with the varying conditions under which each has crystallized.
>
> The anorthosites and gabbros belong to a great series of intrusives which have come up through older gneisses and crystalline limestones. Considered in their entirety, the intrusives embrace other varieties of gabbroic rocks than the two just cited, varieties that lie between them as extremes, but as the intermediate types are not immediately concerned with the ores they are not described in further detail. The

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[a] Kemp, J. F., The titaniferous iron ores of the Adirondacks: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 397-399.

[b] A single exception is the Port Leyden mine in Lewis County, outside of the main gabbro area. The immediate wall rock of the deposit is not exposed, but it seems to be associated with quartz gneisses containing potash feldspar. The anomalous relations of this deposit are probably only apparent and it seems reasonable that, as Newland suggests, "it may be related to some underlying magma from which the ore body represents an offshot, perhaps intrusive in the granitic gneiss." One should hesitate to consider a deposit whose relations to its wall rock are as obscure as in this case an exception to a rule of such general application.

intrusives correspond to the Norian of the Upper Laurentian of the Canadian geologists, and the gneisses and crystalline limestones are the representatives of the Canadian Grenville series. In the nomenclature adopted by the United States Geological Survey, both the older rocks and the intrusives must be included in the Algonkian on account of the presence of the limestones. After the intrusions of the gabbros and anorthosites the Adirondack region was subjected to great dynamic metamorphism, so that the massive rocks were crushed and often drawn out into gneisses, and so involved with the older formations as to greatly obscure the stratigraphical relations. It is rather rare to find one of the Norian massive rocks that does not display some evidence of this metamorphism, but in a few cases limited areas of the dark gabbros have escaped it to a greater or less degree, and in the western part of Essex County the anorthosites are not greatly affected.

DESCRIPTION OF OCCURRENCES IN ELIZABETHTOWN, WESTPORT, AND MORIAH TOWNSHIPS.

Only those occurrences that were visited by the author are described. They include nearly all the more important deposits and are sufficiently characteristic to establish clearly the nature of the ores.

SPLIT ROCK MINE.

The Split Rock mine is located on the west shore of Lake Champlain in a small cove, a half mile above Snake Den Harbor and 5 miles northeast of Westport. It is on a steep hillside overlooking the lake. The hill is a spur of Split Rock Mountain which is a long ridge running parallel to the lake shore.. Split Rock Mountain consists chiefly of anorthosite with some gabbro. The wall rock of the ore is a highly garnetiferous gabbro. The garnet occurs throughout the rock in small clusters of nearly black crystals, giving the rock a peculiar mottled appearance. The plagioclase of the gabbro consists of nuclei swarming with minute inclusions of pyroxene and probably spinel, surrounded by areas of clear feldspar. The garnet tends to occur in the areas of clear feldspar and closely associated with the femic minerals. Cutting the rock and the ore are small dikes of a white rock varying from a few inches to a foot in thickness. In thin section this rock is seen to consist almost entirely of saussurite with a few scattered bunches of augite, garnet, and hornblende.

Three ore bodies outcrop within a distance of 200 feet. The larger of these, which is the more southerly, has a width of about 10 feet. Two openings have been made on this ore body about 20 feet apart. An opening has also been made in the most northerly of the three deposits.

These ore bodies are magnetite-rich lenses into which they grade by gradual transition. Most of the ore is a dark-colored fine-grained rock of seeming good quality, but polished sections show that it is a very lean ore. Plate II, *A*, shows a specimen of the ore that has been polished and then leached with concentrated hydrochloric acid until the gangue minerals are all light colored. The relations and relative quantities of ore minerals and gangue are well brought out. A small amount of coarser-grained ore occurs and this carries little gangue. A peculiar feature of this ore and the ore from Little Pond, which has been described by Kemp, is the occurrence through it, in veinlets and in crusts coating the bounding surfaces of cracks, of a green isotropic material which is presumably a basic glass; the relations of the glass to the ore are such as to indicate a primary origin that is a most anomalous phenomenon in a plutonic rock. The following results of analyses of wall rock and ore are taken from Kemp:

Results of analyses of Split Rock gabbro and ore.

Constituent.	1[a]	2[b]	3[c]
SiO_2	47.88	17.90	16.46
TiO_2	1.20	15.66	14.70
Cr_2O_3	Trace (?)	.51	....
Al_2O_3	18.90	10.23	.34
Fe_2O_3	1.39	15.85	38.43
FeO	10.45	27.94	23.40
NiO.CoO	.02	([d])	([d])
MnO	.16	Little.	.23
CaO	8.36	2.86	3.54
SrO	Trace.	....	....
BaO	Trace.	....	....
MgO	7.10	6.04	2.13
K_2O	.81	([d])	....
Na_2O	2.75	([d])	....
Li_2O	([e])	....	....
H_2O below 110°	.18	1.33	....
H_2O above 110°	.43		....
P_2O_5	.20	.04	....
V_2O_3	Trace.	.55	....
CO_2	.12	.10	....
S	.07	.14	....
	100.02	99.15	....
Fe	....	32.82	32.59
Specific gravity	3.090	4.138	....

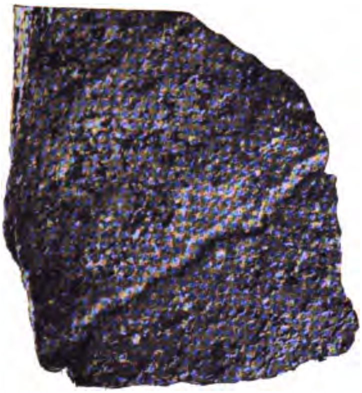
[a] Wall rock; analyst, W. F. Hillebrand.
[b] Ore; analyst, W. F. Hillebrand.
[c] Ore; analyst, G. W. Maynard.
[d] Not determined.
[e] Faint trace.

Analyses 1 and 2 have been recast by Prof. Kemp. Analysis 3 could not be recast on account of the great excess of Fe_2O_3 over FeO.

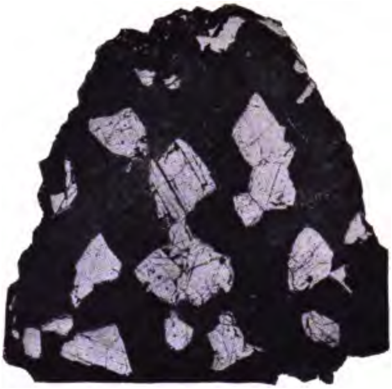
The mineralogical composition of Split Rock ore is presented below:

Mineralogical composition of Split Rock ore and gabbro.

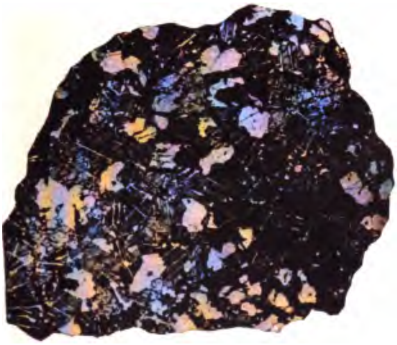
Constituent.	1	2
	Per cent.	*Per cent.*
Ilmenite	2.13	29.42
Magnetite	2.99	22.97
Pyrrhotite	.18	.35
Olivine	16.93	....
Pyroxene	13.41	22.91
Plagioclase	56.70	13.62
Orthoclase	4.45	....
Apatite	.34	....
Calcite	.20	.29
Kaolin	3.10	....
Water	.18	1.33
NiO.CoO	.02	....
Spinel	....	5.97
Corundum	....	.92
V_2O	....	.55
P_2O_5	....	.04



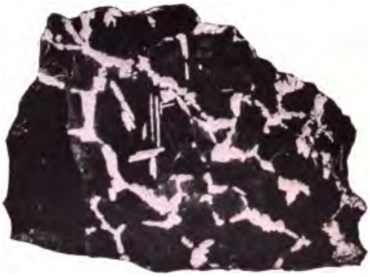
A. SPLIT ROCK, N. Y., ORE. (X 2.)



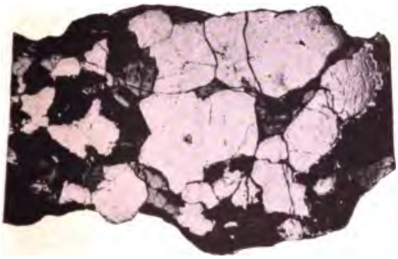
B. MILLPOND, N. Y., ORE. (X 2.)



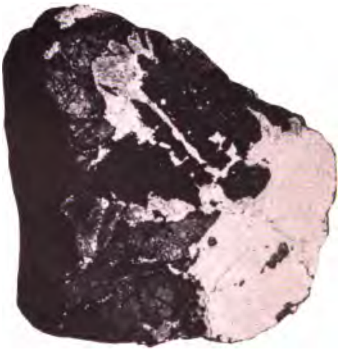
C. TUSCARORA MINE, N. C., ORE. (X 2.)



D. SHANTON RANCH, WYO., ORE. (X 2.)



E. CEBOLLA CREEK, COLO., ORE. (X 2.)



F. CEBOLLA CREEK COLO., ORE. (X 2.)

The percentage of the iron in the ore is very low and the ore would have to be concentrated before it could be used in the furnace. In that event 5.35 per cent of iron, present in the femic minerals of the gangue, would be lost. It would also be desirable to eliminate as much of the ilmenite as possible, and this carries 10.84 per cent of iron. Only 16.63 per cent of iron is present in the form of magnetite, and so far as possible the concentrates should consist only of it. Notwithstanding the low grade of the ore an unsuccessful attempt was made to work it 30 or more years ago, when a dock was built at the foot of the hill and a small magnetic concentrator erected. The small size of the deposit and the leanness of the ore make the deposit of no value.

METALLOGRAPHIC DESCRIPTION OF ORE.

The ore grains in the lean ore range from 0.1 to 1 mm. in diameter and compose 20 to 50 per cent of the surface. Ilmenite grains are somewhat less abundant than magnetite. The magnetite contains comparatively few inclusions of ilmenite, and these are principally lamellæ, forming an open network structure.

The high-grade ore consists of coarser-grained aggregates of magnetite and ilmenite, ranging up to 3 mm. in diameter, and containing little gangue. The ratio between ilmenite and magnetite is about the same as in the leaner ore. The ilmenite intergrowths in the magnetite are much more abundant. These show in section a closely crowded network of 40 or more lines to a millimeter, as in Plate III, *A*, and a network made up of very short dashes. In much of the ore both types are present in the same magnetite grain and there may be a marked tendency for one series of lines to be more prominent and more fully developed than the others. The effect then is the same as that shown for the Little Pond ore in Plate III, *B*.

LITTLE POND MINES.

Two openings have been made in ore bodies near Little Pond, and 2 miles southeast of Elizabethtown. One opening, about a quarter of a mile north of Little Pond, is 20 by 20 feet and 15 feet deep; the other, lying about an eighth of a mile to the southeast, is run into a hillside about 30 feet and has a width of 30 feet and a working face 25 feet high. The country rock is the normal dark-green gabbro, the exposures of which are numerous in the vicinity. Besides the exposures of ore at the two pits, several others were seen in the neighborhood. The outcrops of gabbro between them show that the ore bodies are a number of small segregations, and not an entire hill of ore inexhaustible in amount as has been stated.

The ore is very similar in character to the Split Rock ore just described. Most of it is a fine-grained ore of seeming good quality, but polished sections show that it contains much gangue. A small amount of coarser-grained high-grade ore also occurs. The ore also contains the green glass found in the Split Rock mine. The results of two analyses made by W. F. Hillebrand are taken from Kemp, as follows:

Results of analyses of Little Pond ore.

Constituent.	1[a]	2[b]
	Per cent.	*Per cent.*
TiO_2	18.82	13.07
FeO	29.78	28.35
Fe_2O_3	26.30	11.16
Cr_2O_3	.75	.37
V_2O_5	.62	.50
P_2O_5	Trace.	.32
S	.06	.10
	76.33	53.87
Fe	41.57	29.87
Specific gravity	4.410	3.833

[a] Represents ore from the north pit.

[b] Represents ore from the south pit.

The analyses have been recast by Kemp, as follows:

Partial mineralogical composition of Little Pond ore.

Constituent.	1	2
	Per cent.	*Per cent.*
Ilmenite	35.27	24.49
Magnetite	38.05	16.24
Chromite	.64	.45
Pyrrhotite	.18	.26

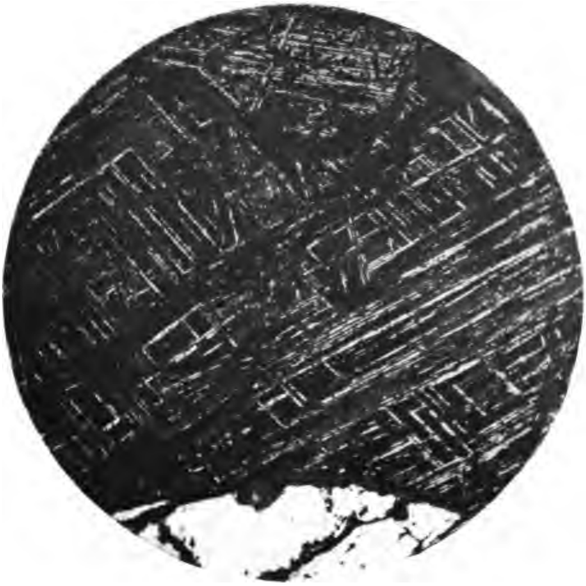
METALLOGRAPHIC DESCRIPTION OF ORE.

The description given of the Split Rock ore can be applied to this ore with little modification. It averages a little coarser grained and the ilmenite intergrowths in the magnetite are not as closely packed. The more usual spacing is 8 to 15 lines per millimeter. There is also the tendency for one series of lines to be more prominent than the others. An interesting type is where one set of lamellæ are heavy and widely spaced, and the other two sets are made up principally of minute, closely crowded dashes. Such a structure is shown in Plate III, *B*.

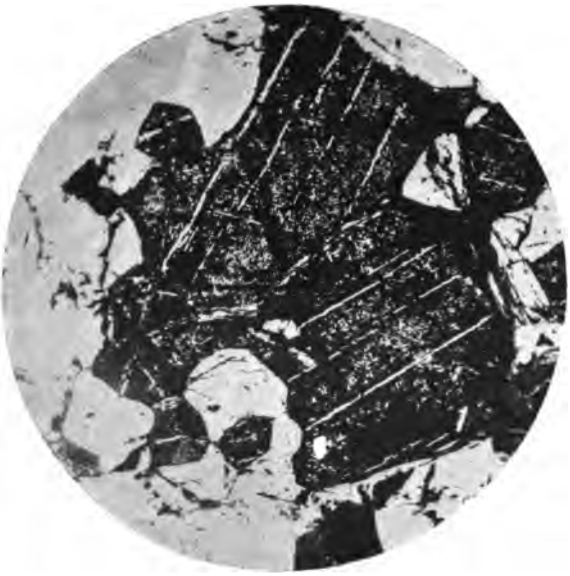
TUNNEL MOUNTAIN MINES.

The Tunnel Mountain mines are situated a mile to a mile and a half southeast of Little Pond, and 3½ miles southeast of Elizabethtown. Near the foot of the southeast side of the mountain are two small pits, about 200 yards apart, showing lean ore. Lack of exposures make it impossible to determine the extent of the deposits.

The largest opening occurs on the western edge of the extreme summit of the mountain, where a pit 40 feet long, 10 feet wide, and 40 to 50 feet deep has been made. Two hundred feet below the summit



A. SPLIT ROCK, N. Y., ORE. (X 60.)



B. LITTLE POND, N. Y., ORE. (X 60.)

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and south of the pit an adit was commenced and run in about 100 or 150 feet. From this tunnel the mountain received its name. The ore body exposed here has a length of about 300 feet and a width of 100 feet. Beyond the exposure it passes over into the country rock. The latter is described by Kemp as a gneissoid norite with hypersthene the most prominent bisilicate. The other components are green augite, brown hornblende, plagioclase, and garnet. Thin sections of the ore reveal, besides the ore minerals, brown hornblende, serpentinized olivine, garnet, and colorless transparent labradorite.

The ore ranges from medium to fine grained, and like all ore of that kind appears richer in hand specimens than is actually the case. Polished specimens show the presence of a large amount of gangue. The following are the results of two analyses by W. F. Hillebrand, taken from Kemp:

Results of analyses of Tunnel Mountain ores.

Constituent.	1[a]	2[b]
	Per cent.	*Per cent.*
TiO_2	16.45	10.55
FeO	28.82	21.34
Fe_2O_3	20.35	11.52
SiO_2	13.35	....
Al_2O_3	8.75	....
Cr_2O_3	.55	.25
CaO	2.15	....
MgO	6.63	....
V_2O_5	.61	.34
P_2O_5	.02	.46
S	.09	.10
H_2O	1.68	....
CO_2	.17	....
C	Trace.	....
Cl	Little.	....
	99.62	....
Fe	35.99	24.65

[a] Represents ore from the deposit at the top of the mountain.
[b] Represents ore from one of the pits near the foot of the mountain.

These analyses, recast by Kemp, are as follows:

Mineralogical composition of Tunnel Mountain ore.

Constituent.	1	2
	Per cent.	*Per cent.*
Ilmenite	30.80	25.344
Magnetite	29.80	16.704
Chromite	.64	....
Anorthite	9.45	....
Spinel	7.38	....
Olivine	6.94	....
Enstatite	11.40	....
Calcite	.40	....
Water	1.68	....
Vanadic acid	.61	....
Sulphur	.09	....
Phosphorus	.02	....
Residue SiO_2	.36	....
Remaining FeO	....	6.912
	99.57	

METALLOGRAPHIC DESCRIPTION OF ORE.

Gangue constitutes from 25 to more than 50 per cent of the surface of the ore. The magnetite grains are about twice as abundant as the ilmenite, though in places the ilmenite is nearly as abundant as the magnetite. Few grains exceed 1½ mm. in diameter. Regular intergrowths of ilmenite lamellæ in the magnetite are not very abundant, and where they do occur they form a very open structure and are rather thin. Many of the magnetite grains, on the other hand, are swarming with minute inclusions of ilmenite which at times show a tendency to orient along parallel lines, suggesting the incipient development of a network structure. This type of ilmenite inclusion is discussed more fully and illustrated in connection with the description of the metallographic features of the Minnesota ores.

LINCOLN POND MINE.

Three-quarters of a mile southwest of the road crossing the lower end of Lincoln Pond, and a quarter of a mile back from the pond, is an open cut into a steep cliff of gabbro, which is known as the Lincoln Pond or Kent mine. The location is 5 miles northwest of Mineville. The opening is 15 feet wide and nearly 100 feet long. At the far end a shaft was put down, but this is now filled with water, so that its depth could not be determined at the time of inspection. The opening shows little ore, the principal showing being on the left side at the far end. There is a gradual transition from gabbro to ore without any change in the size of the constituent mineral grains. Both ore and rock are fine grained. The rock is described by Kemp as varying from a true norite to a gabbro with accessory hypersthene. Garnet may or may not be present, and in some places is rather abundant. It assumes at times a peculiar fingerlike development in the plagioclase, a feature that has been noticed at other places in the Adirondack gabbros.

About 50 feet beyond this opening is a small opening in which is exposed high-grade coarse-grained ore resembling in appearance the ore in the anorthosites. The contact between this ore and the gabbro is sharp and lacking in a transitional zone.

The following results of analyses of wall rock and ore are available:

Results of analyses of Lincoln Pond ores and wall rock.

Constituent.	1[a]	2[b]	3[c]	4[d]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	44.77	11.73	4.73	....
TiO_2	5.26	12.31	2.58	5.88
Al_2O_3	12.46	6.46	....	....
Fe_2O_3	4.63	30.68	....	....
FeO	12.99	27.92	....	....
NiO.CoO	Trace.	([e])	....	....
MnO	.17	([e])	.05	....
CaO	10.20	3.95	....	....
[illegible]	Trace.	....	....	....
MgO	5.34	3.35	....	....
K_2O	.95	.26	....	....
Na_2O	2.47	.50	....	....
H_2O below 100°	.12	....	....	....
H_2O above 100°	.48	.64	....	....
P_2O_5	.28	.82	1.074	....
V_2O_5	([e])	.04	....	....
CO_2	.37	.32	....	....
S	.26	.04	.272	....
C	....	.05	....	....
Cl	....	.12	....	....
F	....	Trace.	....	....
	100.75	99.19	....	....
Fe	....	44.19	59.26	64.66
Specific gravity	3.090	4.138	....	....

[a] Represents wall rock. Analyst, George Steiger. (See Kemp, J. F., The titaniferous iron ores of the Adirondacks: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 407.

[b] Represents ore. Analyst, W. F. Hillebrand. (See Kemp, J. F., op. cit, p. 407.)

[c] Represents ore. Figures furnished by W. L. Cumings of the Bethlehem Steel Co.

[d] Represents coarse-grained high-grade ore taken from the small pit. Results were calculated from results of analyses by A. C. Fieldner, of the Bureau of Mines, of concentrates and tailings of a magnetic separation.

[e] Not determined.

The high phosphorus content of the ore is noteworthy and is corroborated by the abundant apatite seen in thin sections. Another feature commented on by Kemp is the presence of carbon. Traces of carbon were found in the ores from some of the other localities, and in this case it amounts to 0.05 per cent. Hillebrand inferred the presence of graphite, though this could not be unquestionably established. Of the three ore analyses, analysis 2 alone represents the normal titaniferous ore in the gabbro. Its iron content is somewhat higher than the average for the region.

Analyses 1 and 2 have been recast by Kemp with the following results:

Mineralogical composition of Lincoln Pond gabbro and ore.

Constituent.	1	2
	Per cent.	*Per cent.*
Ilmenite	9.73	22.95
Magnetite	6.73	44.31
Pyrrhotite	.65	.09
Apatite	.67	1.74
Olivine	2.93	7.83
Pyroxene	32.71	5.01
Plagioclase	37.36	12.53
Orthoclase	5.00	....
Kaolin	3.60	....
Calcite	.90	....
Spinel	....	3.55

METALLOGRAPHIC DESCRIPTION OF ORE.

The fine-grained lean ore of this occurrence is similar to the ore from other occurrences of the region previously described. On the polished surfaces examined ilmenite intergrowths in the magnetite are not very abundant and consist chiefly of swarms of minute dots. Such line structure as is developed is caused by widely scattered lamellæ, so that the intersecting-line pattern is not prominent. The individual ore grains of the coarser ore reach a diameter of 5 mm. or even more in a few cases, but the average is between 2 and 3 mm. Gangue minerals are almost lacking. Polished sections of this ore differ decidedly in appearance from most coarse-grained titaniferous magnetites. Instead of the sharp contrast between the bright surfaces of the ilmenite grains and the dull faces of the magnetite most of the surface, on being etched, takes on an iron-gray to silver-gray color. Bright surfaces of ilmenite grains occur only sparingly. The duller grains of magnetite show an open-line structure in which the lines are not usually continuous, but are made up of a series of dashes as shown in Plate IV, *A*. This figure also shows the film of ilmenite that frequently outlines the magnetite grains. The more lustrous grains have the silvery, mottled appearance of nontitaniferous magnetites. They differ from such, however, in that in places this mottled effect loses its irregularity and takes on a linear arrangement. Hence the mottling may be due to minute ilmenite inclusions possessing no regular orientation.

The results of a magnetic separation and analysis of the products of a sample of the coarse ore bear out the above metallographic description of it. These results follow:

Results of magnetic concentration and analysis of Lincoln Pond ore.

	Unscreened ore.	Ore through 50-mesh, over 100-mesh.[a]		Magnetic ore through screen finer than 100-mesh.[b]
		Magnetic.	Non-magnetic.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity	....	96	4	95.6
Fe	64.66	66.08	30.59	66.27
TiO_2	5.88	4.82	31.45	5.12

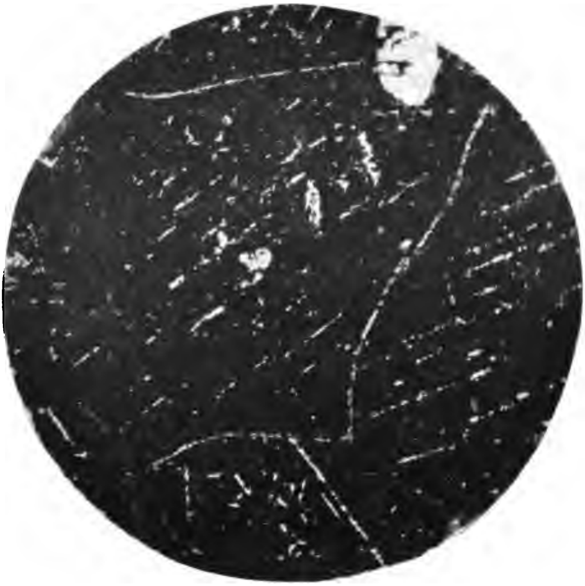
[a] 46.9 per cent.

[b] 53.1 per cent.

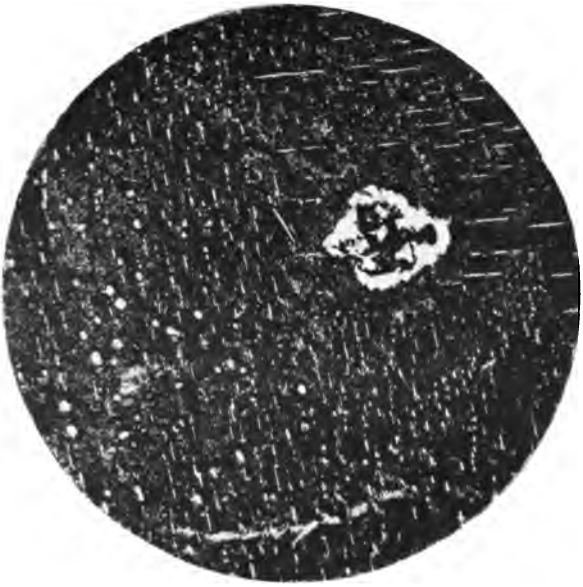
It is thus seen that the ore is low in titanium and that only 2.4 per cent of ilmenite was separable.

DALTON ORE.

A deposit known as the Dalton ore has recently been prospected by Witherbee, Sherman & Co. by means of diamond drilling and a



A. LINCOLN POND, N. Y., ORE. (× 60.)



B. MILLPOND, N. Y., ORE. (× 60.)

small pit. It is situated about 1 mile northwest of Feeder Pond and 5½ miles west of Mineville, high up on the east slope of Ash Craft Brook. The pit is on the main ore body and is 20 by 10 feet by 5 feet deep. The relations of the ore bodies to the country rock are well exposed here and hence the deposit is of unusual interest. The country rock is a greenish gabbro with considerable dark, nearly black garnet. The garnet occurs in numerous small clusters producing a rock resembling the garnet-rich gabbro of the Split Rock mine. The ore outcrops occur within an area about 300 feet long parallel to the valley and 100 feet wide. At the southwest end of this area the gabbro is cut by a small pegmatite dike.

The ores are much richer than the average of the region and also differ in that there is no transition of gabbro into ore, so that the ore can not be considered an iron-rich phase of the gabbro, but it appears in distinct schlierenlike masses which seem to have been injected into their present position while the gabbro was still in a molten condition. The contact between the ore and the wall rock is marked by a distinct garnet-rich zone. The ores occur in narrow veinlets less than an inch in width, increasing in size to larger masses which, in the case of the main ore body, attain a width of 40 feet. The small veinlets are usually homogeneous in character and free from inclusions of country rock; the larger masses may have irregular outlines and also contain inclusions of country rock. The gabbro in the vicinity is much sheared and the ore tends to lie parallel to the schistosity, though some veins plainly cut across the schistosity.

The ore contains little gangue and this in some places is principally feldspar and at others principally femic minerals. It is about as coarse grained as the ore in the anorthosite, which it much resembles in the hand specimen. The following results of analyses, with the exception of the last, were furnished by Mr. Le Fevre of Witherbee, Sherman & Co. The results last given were furnished by W. L. Cumings of the Bethlehem Steel Co.:

Results of analyses of Dalton ore.

Constituent.	1		3	4	5		7
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	52.20	47.79	50.46	47.71	48.00	56.03	57.71
TiO_2	7.12	7.53	11.47	5.62	7.58	7.72	3.90
P	.020	.042	.017	.026	.060	.014	.048
S	....	....	....	....	....	....	.022
SiO_2	....	....	....	....	....	....	4.95
Mn	....	....	....	....	....	....	.07

The percentage of iron and titanium in this ore is similar to that of the coarse-grained Lincoln Pond ore. In megascopic appearance they are much alike. Though not as well exposed at Lincoln Pond as here, it was noticed there also that the contact between rich ore and country rock was sharp and not transitional. Geologically the coarse-grained Lincoln Pond ore would seem to be identical with the Dalton ore.

METALLOGRAPHIC DESCRIPTION OF ORE.

The similarity of the Dalton ore and the coarse-grained Lincoln Pond ore in geologic occurrence, in appearance, and in composition is likewise shown in microstructure. Large grains of ilmenite are more abundant in the Dalton ore, but the appearance of the etched magnetite is nearly the same. Some of the duller magnetite grains show a tendency to rectilinear arrangement of ilmenite intergrowths which are not continuous lines but a series of dashes as illustrated in Plate IV, *A*. The triangular network is faintly developed in a few places. The greater part of the magnetite has the grayish, mottled appearance described in discussing the Lincoln Pond ore.

This ore and the coarse-grained Lincoln Pond ore differ from the other occurrences of the gabbro in this region in the relation of the ore to the wall rock, in the higher iron content and lower titanium content, and in the lack of distinctiveness of the ilmenite intergrowths in the magnetite. Their metallographic features suggest a close relation to the low-titanium ores in the syenite, such as occur at the Nigger Hill mine on the mountain northwest of Lincoln Pond.

POSSIBILITIES OF UTILIZING THE ORES IN THE GABBRO.

All of the deposits in the three townships just discussed occur in the gabbros, and with two exceptions show the same general characteristics. .Further, these characteristics differ sufficiently from those of the ores in the anorthosite to make a separate discussion of their commercial possibilities necessary. As the ores in Newcomb Township, which are next described, occur principally in the anorthosite, the economic aspect of the ores in the gabbro is considered at this point.

The facts in regard to the individual deposits have been stated in the foregoing detailed descriptions. It is now desired to give a comprehensive statement of the possibilities of this class of ores considered as a whole. This phase of the question is so well presented by Kemp [a] that his opinion is quoted verbatim in the following paragraphs:

> Enough analyses are now in hand to illustrate in a satisfactory manner what may be expected. The percentage in iron, titanic oxide, phosphorus, and sulphur may be first summarized with the name of the sampler.

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[a] Kemp, J. F., Geology of the Elizabethtown and Port Henry quadrangles: N. Y. State Mus. Bull. 138, 1910, pp. 147-149.

Results of analyses of ores from the Adirondack region.

Source of ore.	Sampler.	Fe.	TiO_2.	P.	S.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Split Rock	J. F. Kemp	32.82	15.66	0.017	0.14
Do	G. W. Maynard	32.59	14.70	....	....
Tryan Pit	J. F. Kemp	24.65	10.55	.20	.10
Tunnel Mountain	.....do	35.99	16.42	.009	.09
Little Pond	.....do	41.57	18.82	Trace.	.06
Do	.....do	29.87	13.07	.14	.10
Lincoln Pond	.....do	44.19	12.31	.36	.04
Oak Hill	.....do	38.98	5.21	.06	.04
Kingdom Works	G. W. Maynard	32.59	13.15	....	....
Iron Mountain	J. F. Kemp	40.42	16.37	....	....

It is at once apparent that all of these ores are extremely low grade, the richest being 44.19 and only two others reaching 40. Since under present conditions and those which are likely to continue for many years no magnetite under 50 per cent in iron is of importance as a source of lump ore, unless it should have exceptional purity in phosphorus and sulphur, be lacking in titanium, and be in addition located near a furnace, there is little encouragement to look with favor upon bodies of this type.

The percentages in phosphorus and sulphur are also important features. In sulphur the ores are obviously low. In phosphorus they are variable. In instances such as Split Rock and Tunnel Mountain they are very low; in others they are quite high, as at Lincoln Pond. There is a somewhat widely prevalent impression that the titaniferous ores always run low in phosphorus and sulphur, but this is clearly unjustified. As with other ores each case must be sampled by itself.

The presence of vanadium in these ores is a matter of much scientific interest, and since the element has come into such extended use for high-grade steels some have looked to the titaniferous ores as possible sources. If we summarize the results given above, we obtain:

	V_2O_5.
Split Rock	0.55
Tryan Pit	.34
Tunnel Mountain	.61
Lincoln Pond	.62
Little Pond	.50
Do	.04

In just what form the vanadium is combined is unknown. From its chemical properties similar to phosphorus one would suspect some compound analogous to apatite, just as we have pyromorphite and vanadinite, but although the vanadic oxide exceeds in amount the phosphoric, the mineral containing it has never been isolated.

Ferrovanadium is manufactured from vanadium compounds by electrical processes and contains about 25 to 27 per cent of this element. It would appear as if the percentage of this valuable substance were too low to make it a serious factor in the value of the ore, but as the industry of vanadium is as yet in its infancy one should speak regarding its future in a conservative spirit. In a vanadium steel now so higly prized for its toughness there is much less than 1 per cent vanadium. Elementary vanadium constitutes 77.4 per cent of vanadic oxide (V_2O_5).

Magnetic iron ores under 50 per cent and not fulfilling the conditions stated above must undergo magnetic concentration if they are to be utilized. It is with regard to this method of treatment that the recasting of the analyses into percentages of ilmenite and magnetite has especial significance. The magnetite would be the mineral saved and the one upon which efforts would be especially expended. The iron in the ilmenite we would expect, if not hope, to lose, so as to reduce the titanium. The iron in the pyroxene and olivine would pass off in the nonmagnetic tailings. So far as iron is concerned we are therefore reduced to considering along the magnetite, and therefore the following tabular summary is presented:

Mineralogical composition of Adirondack ores.

Source of ore.	Ilmenite.	Magnetite.	Iron in magnetite.
Split Rock	29.42	22.97	16.63
Do	27.95	32.8	23.74
Tryan Pit	25.34	16.71	12.10
Tunnel Mountain	30.80	29.80	21.58
Little Pond	35.27	38.05	27.55
Do	24.49	16.24	11.76
Lincoln Pond	22.95	44.31	32.08
Oak Hill	9.70	44.08	31.91
Kingdom Works	24.64	31.08	22.50
Iron Mountain, Elizabethtown	30.80	35.73	25.86

These results show that even if the ilmenite and magnetite are so coarsely intergrown as to make a separation feasible the grade of the ore is too low to make the separation a likely source of profit. On the other hand, the ore is extremely hard and fine grained, quite different from the richer and more coarsely crystallized occurrences at Lake Sanford, and parallels can not be justly drawn. While the concentrates would doubtless be somewhat enriched in iron by ilmenite which would enter them, they would be decreased by some inevitable losses in magnetite, and by just so much as the titanium exceeded a very small value, say 1 per cent, the operators of iron furnaces under present slag calculations would regard them unfavorably.

The conclusion is quite irresistible that only by smelting in the crude or lump form, and by the development of a process which does not find titanium objectionable, and under conditions where ores of iron content of 35 to 45 could be utilized, can these deposits be made available.

That these ores hold out small economic possibilities for some time to come can be demonstrated by other considerations not mentioned above. With only one or two exceptions they are at present inaccessible to proper transportation facilities. To provide them with such would involve an expense that would be warranted only in connection with very large deposits. From the nature of the deposits there is no reason to expect the third dimension, or the extension in depth, to be any greater than the larger of the two surface dimensions. Wherever the areal extent of the deposits can be determined it is either small or, if large, its size is not due to the presence of a single large ore body, but to a series of small deposits, between which are areas of barren country rock. Adding to this difficulty the leanness of the ores, which makes the erecting of a concentrating plant necessary, and their titaniferous character, the hope of utilizing these ores within any reasonable period in the future is by no means bright.

DESCRIPTION OF OCCURRENCES IN NEWCOMB TOWNSHIP.

Several titaniferous ore bodies occur in this township, near the headwaters of the Hudson River, in the neighborhood of Henderson and Sanford Lakes. The position of these ore bodies is shown in

Plate V.[a] They include the largest bodies of titaniferous iron ore in the Adirondacks, and one of them, the Sanford ore bed, is exceeded in size by only one other deposit in the United States, that of Iron Mountain, Wyo.

As this region was at one time the seat of the most extensive operations yet conducted on titaniferous ores in this country, a brief historical sketch taken from Newland[b] is of interest here. The sketch follows:

> The site of the former Adirondack village (now occupied by the Tahawus Club), which was built by the early ironworkers, lies in the midst of a wild, heavily forested region, shut in by high elevations on all sides except the south, where the river has worn a narrow valley. North Creek, the terminus of the Adirondack branch of the Delaware & Hudson Railroad, is about 30 miles distant by wagon road, and Port Henry, on Lake Champlain, about 50 miles.
>
> Unusual interest attaches to the events connected with the first developments of the Lake Sanford deposits and the establishment of the local iron-making enterprise to utilize the ores.[c] Following the discovery, which is reported to have been made in 1826, a tract of land comprising the deposits was secured from the State by Mr. A. McIntyre and associates who soon after began active work. The investigations of Prof. Emmons in connection with the geological survey of New York then in progress no doubt gave a stimulus to the undertaking. Prof. Emmons published in his reports an extended account of the ore bodies, which he recognized to be of enormous size and regarded as eminently adapted to utilization. He recommended the location of iron-manufacturing enterprises in the vicinity. Soon after the publication of his first report, or about 1840, a blast furnace of 3 or 4 tons daily capacity was built and placed in operation. This was afterwards remodeled so as to enlarge its capacity, and a second furnace of 12 to 15 tons was put in blast in 1854. Drawings of the large stack, which remains to the present day, with all its essential features have been made by Mr. Rossi and published in the article already referred to. The installation included also puddling furnaces and the necessary equipment for making bar iron. The works were closed down in 1856, after which they were not again operated for any length of time. The product of the furnaces was hauled over a difficult mountain road to Crown Point for shipment, and the expense of transportation must have been a heavy tax upon the enterprise.
>
> There seems to be little doubt, judging from all accounts, that the iron turned out in the early days was of good quality; in fact it was especially commended by Emmons and others; nor does it appear that the sudden termination of iron making was due to metallurgical difficulties in reducing the ore, though it is probable that the operators, at least in the early years, were unaware of the titaniferous character of the material. From considerations based on an analysis of slag, which was taken from the dump near the old furnace, Mr. Rossi has expressed the opinion that the furnace charges were made up on somewhat different lines than usually practiced in that a proportion of the country rock (anorthosite) was added to the limestone for flux. It may be noted, however, that the crude ore such as was employed in the operations contains more or less of admixed rock, so that the presence of the latter may have been accidental rather than intentional.

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[a] The map comprising this plate is a reproduction, with slight correction, of Plate 15 of N. Y. State Mus. Bull. 119.

[b] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, pp. 155-156.

[c] A good historical account of the discovery and exploitation of the deposits will be found in Watson's "History of Essex County." The reports by Emmons contain a description of developments up to 1840, For details as to the blast furnaces and metallurgical operations consult Rossi, "Titaniferous Ores in the Blast Furnace": Trans. Am. Inst. Min. Eng., vol. 21, 1892-93.

After lying idle for 50 years the property was taken over in 1907 by a new organization * * * with a view to the exploitation of the ores. This company has conducted a thorough investigation and intends to enter upon active mining in the near future. The construction of a railroad is a requisite before commercial shipments can be made.

GENERAL FIELD RELATIONS.

The area under consideration lies within the main anorthosite area of the Adirondacks, near its western boundary. With one or two exceptions where the ore occurs in gabbros, the anorthosite forms the country rock of the deposits.

In its typical development, the anorthosite is a nearly pure plagioclase rock in which labradorite is the predominant feldspar. The texture of the rock is coarsely granitoid, and the length of the feldspar crystals may reach several inches. It is most commonly light blue in color, but at times it is yellow and even black. Usually little else than the feldspar can be recognized macroscopically. In thin section, however, augite, hypersthene, and magnetite are seen as accessory constituents in widely varying amounts. Magnetite and ilmenite are far less abundant in this rock than in the gabbros. The anorthosite has resisted crushing and mashing to a far greater extent than the gabbros, and gneissic varieties are not so common. Where crushing has taken place, garnet, biotite, and calcite are developed as secondary minerals. No results of analysis of the anorthosite of this area are available, but the analysis whose results are given below was made by Prof. Albert R. Leeds[a] of a sample taken from the summit of Mount Marcy.

Results of analysis of anorthosite from Mount Marcy.

Constituent.	Per cent.
SiO_2	54.47
Al_2O_3	26.45
Fe_2O_3	1.30
FeO	.67
CaO	10.80
MgO	.69
Na_2O	4.37
K_2O	.92
Loss	.53

In a few places within the ore-bearing area the typical anorthosite gives way to a fine-grained rock in which the femic minerals are more abundant, forming a gradation to gabbro. This rock seems to have been less resistant to metamorphism and in many places shows a gneissic structure. In such cases it contains considerable hornblende derived from the pyroxene and much garnet. The rock is undoubtedly a phase of the anorthosite, but in some cases is not a differentiation in situ but has been intruded into its present position in the anorthosite in the form of dikes.

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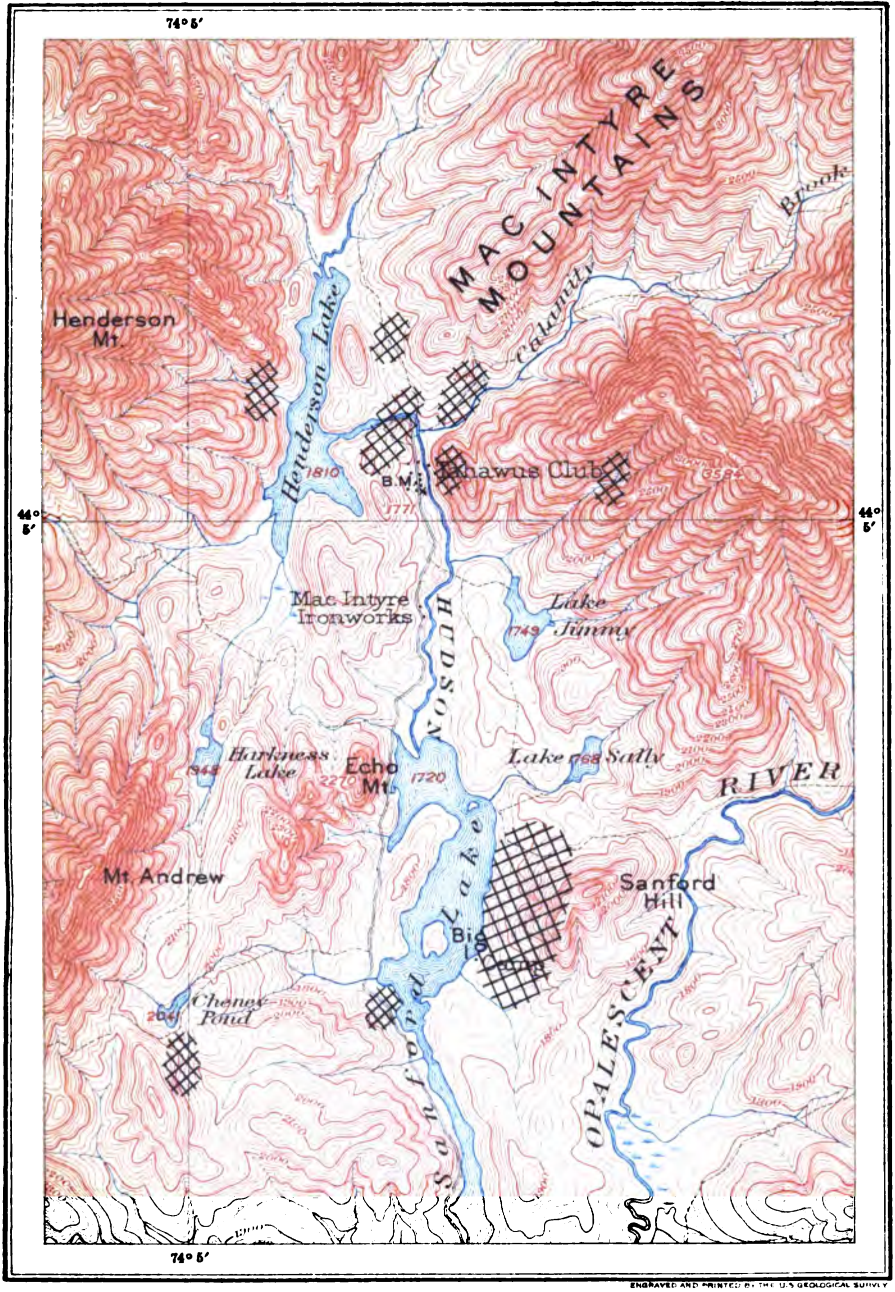
[a] 30th Ann. Rept. N. Y. State Mus., 1878, p. 92.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

MAP OF THE VICINITY OF LAKE SANFORD, NEW YORK

ORE BODIES ARE INDICATED BY CROSS HATCHING

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

DESCRIPTION OF ORE DEPOSITS.

Ore occurs in both the anorthosite and the gabbro, but in this area the anorthosite is the more common wall rock. The ores in the gabbro are very similar to the ores in that rock in Westport, Elizabethtown, and Moriah Townships. Their geological occurrence and their chemical composition are about the same.

The ores in the anorthosite are of more uniform character and of higher grade in iron, and also coarser grained. The gradual transition from wall rock to ore so common in the gabbros is usually lacking. Anorthosite and ore are in most cases in sharp contact, with little if any increase in the amount of femic minerals in the anorthosite as the ore is approached. There seems to have been a complete differentiation of the ferruginous and titaniferous minerals on the one hand and the feldspathic on the other. In the one rock, iron oxide and titanium oxide crystallized by themselves; in the other, silica, alumina, soda, and lime. The intermediate femic silicates formed in small amount, a condition that Kemp suggests was due to the lack of magnesia. The ore carries a very small percentage of gangue, but in many places contains crystals of labradorite, which may attain considerable size. The feldspar is, however, never in actual contact with the ore minerals, but is separated from them by a narrow zone of fine-grained femic silicates. Further details in regard to the character of the deposits are given in the descriptions of the individual deposits.

DESCRIPTION OF DEPOSITS IN GABBRO.

CHENEY POND ORE.

The Cheney Pond deposit is situated near the south end of Cheney Pond, a little over a mile west of the road running along Sanford Lake. About 350 yards south of the lake is a pit 35 feet wide and 20 to 30 feet deep. Between this pit and the lake several diamond-drill holes were put in a few years ago. The cores of the drill supply information not otherwise obtainable on account of the lack of fresh rock exposures.

The rock is a gabbro gneiss which is very crumbly on weathered surfaces. Garnet and magnetite are prominent constituents throughout the rock. With increasing amounts of magnetite the rock grades over into ore. A thin section of the average grade of ore shows the ore minerals and plagioclase as the most abundant constituents, with the ore minerals forming about 50 per cent of the rock. Augite and garnet are also prominent. Less abundant are biotite, apatite, and dark-green spinel. The garnet and pyroxene tend to occur around the periphery of the feldspar crystals. Frequently the augite is replaced to a great extent by hornblende. Though most of the ore is rather lean, there is a little high-grade ore in which there is only a small amount of gangue. The drill cores show that the gabbro grades over into anorthositic rock, so that at this locality the gabbro is merely a basic phase of the anorthosite and not an intrusive dike.

The results of two analyses of the ore from the pit have been published. One of these represents the average lean ore; the other must have been made from a sample of the richer phase and does not represent the run of these deposits.

Results of analyses of Cheney pit ore.

Constituent.	1	2
	Per cent.	*Per cent.*
TiO_2	8.25	15.77
Fe_3O_4	86.53	55.64
SiO_2		9.79
Al_2O_3		7.12
CaO		8.89
MgO		3.00
P	.39	
S	.74	1.00
Fe	62.15	40.33

The second analysis represents about the same composition as the ores in the gabbro in the townships to the east described on preceding pages.

Metallographic description of ore.—The microscopic structure of the ore presents little of interest. The size of the grain is roughly proportional to the richness of the ore. In the higher grade ores, ilmenite and magnetite grains attain dimensions of 4 mm.; in the leaner ores they scarcely reach 2 mm. and average considerably less. The ratio of ilmenite to magnetite is variable; some sections show nearly all ilmenite, others only a small amount. The average of all the sections examined shows the ilmenite somewhat in excess of the magnetite.

A surprising feature of the magnetite is the almost entire absence of ilmenite lamellæ intergrown in it. Only here and there was a line or two seen in the magnetite. On the other hand the swarms of minute ilmenite particles possessing no regular orientation and giving the magnetite a gray, mottled appearance are abundant. Besides these there occur large circular dots in dull magnetite grains.

On the whole what has been said regarding the possibilities of utilizing the ores in the gabbro applies to this deposit, except that it seems to be considerably larger than the average.

OTHER OCCURRENCES IN GABBRO.

Exposures of iron ore in fine-grained gabbro occur along Calamity Brook for some distance above its mouth. The ore is first encountered about 200 feet above the mouth of the stream on the north side, where it plainly cuts the anorthosite. About 100 feet above this point another dike cuts across the brook in a northeasterly direction. For two or three hundred yards there is an alternation of this fine-grained rock and anorthosite. In places the contact between the two is a straight line, in others the boundary is irregular. In either case, however, the boundary is usually sharp and lacking in a transitional zone. At some of these contacts the evidence that they are intrusive is unmistakable. The rock is characterized by an abundance of magnetite and ilmenite and by the small amount of feldspar that it contains. Considerable pyrite is also present. A thin section of a richer phase of the rock shows besides the ore minerals augite and hypersthene as the most prominent constituents, a little biotite and spinel being noticeable. Locally the ore minerals become abundant enough to consider the rock a lean ore. On account of the fine grain and the lack of salic minerals, the rock has a black appearance which makes it look to be much richer than it really is.

The occurrence one mile east of the Tahawus Club, high up on the mountain slope, is more like the Cheney Pond ore in that it carries considerable plagioclase.

Some of the ore on the north side of the Hudson River between the bend and Lake Henderson is fine grained and lean, due to the presence of abundant femic minerals. This is especially so toward the west end of the ore-bearing area. Some of the drill cores show an alternation of fine-grained lean ore and coarse-grained high-grade ore. The following section of one of these cores is given by Newland:[a]

Section from diamond-drill core from bore hole on north side of the Hudson River near Lake Henderson.

	Ft.	in.
Lean ore, consisting of disseminated magnetite with feldspar and pyroxene..	19	3
Rich ore	30	6
Rock and lean ore, alternating	15	..
Rich ore	33	6
Rock carrying some ore	11	1
Lean ore	12	..
Rock and lean ore	8	..
Rich ore alternating with seams of rock	10	7
Rock	5	..
	144	11

Though not so stated, what is called lean ore in this record is doubtless of the fine-grained gabbroitic variety.

DESCRIPTION OF ORES IN ANORTHOSITE.

The ores in the anorthosite attain their chief development along the Hudson River between the Tahawus Club and Henderson Lake and on the west side of Sanford Hill overlooking Sanford Lake. The former area was the principal source of ore for the early iron works operated here, and the pit from which the ore was taken is called the Millpond pit.

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[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, p. 162.

MILLPOND ORE.

The Millpond pit is on the west side of the river directly opposite the mouth of Calamity Brook. It is an opening about 100 feet long and 12 to 40 feet wide, now filled with water. The lower part of the walls of the opening just above the level of the water shows a coarse-grained high-grade ore, nearly free from visible gangue minerals. The upper part of the walls around the rim of the opening consists of typical anorthosite. The contact between the two is, therefore, well exposed. The boundary is irregular in its outline, but sharp. Pure ore usually extends up to the very contact. The anorthosite at times contains small patches of ore surrounded by reaction rims. The intermingling, however, is by no means sufficient to suggest a transition from ore to wall rock.

The reaction rims between the feldspar and the magnetite are most beautifully developed both around feldspar inclusions in the ore and around ore inclusions in the feldspar in this area and on Sanford Hill. The nature of the rims varies considerably. A thin section from the Millpond pit showed a well-developed three-zone reaction rim. The large feldspar crystals swarmed with minute green spinels and acicular pyroxenes to such an extent as to render the feldspar so cloudy that the twinning bands are nearly obscured. Around this nucleus is a zone consisting of clear feldspar, pyroxene, and larger spinel individuals. The feldspar and pyroxenes occur as a matrix inclosing the abundant spinel. The second zone consists of a clear monoclinic pyroxene with very faint greenish tinge. Along fracture and cleavage lines a small amount of magnetite occurs. The third zone consists of a pyroxene of a darker green color, the fractures of which are heavily filled with magnetite. Beyond this zone is the magnetite. The width of the rim where the three zones are best developed is 1 mm.; where it becomes wider the zones lose their distinctness.

Another thin section from a specimen across the river from the Millpond pit showed a different development, though it, too, had three distinct zones. The feldspar is likewise clouded by minute inclusions, but running through it in long fingerlike and vermicular shapes are garnet crystals. The feldspar immediately adjacent to the garnet and, where the garnet had developed abundantly, whole areas of it are perfectly clear, indicating that the garnet is the product of a reaction between the feldspar and the minute inclusions. Surrounding these nuclei of feldspar is always a zone of clear feldspar and garnet. Next comes a narrow zone of clear feldspar nearly free from any other minerals. In the third zone feldspar is nearly lacking, and the principal minerals are augite, biotite, and chlorite. Beyond this zone is the magnetite, which contains abundant inclusions of dark-green spinel. As in the previous case, the zones are most distinct where the reaction rim is not too wide.

Surface exposures of the ore do not indicate as extensive an area as shown by Newland (Pl. V). Fifty feet west of the Millpond pit is an exposure of anorthosite that is practically continuous to the top of the small knoll between the river and Henderson Lake. It may be that Newland's boundary is based on magnetic surveys. At the Millpond pit the ore is overlain by anorthosite, and it is quite possible that the ore body continues westward under the knoll of anorthosite.

The "Iron Dam" is a riffle across the river a short distance below the Millpond pit, on the surface of which considerable ore is exposed. The ore is of the same coarse-grained character as that of the Millpond pit, but large feldspar phenocrysts are more abundant. It occurs in the form of several larger lenticular bodies and numerous small stringers running through the anorthosite. The relations at the contact of ore and country rock are the same as those described as existing at the Millpond pit. On the east side of the river, between Calamity Brook and the sharp bend above it, are numerous exposures; most of them are of anorthosite. At several places, however, the anorthosite contains small lenticular and irregular shaped ore bodies and stringers of high-grade coarse-grained ore, exhibiting the same relations as the similar occurrences at the "Iron Dam."

The contact between the ore and the wall rock is exposed so often and so well at the localities just described that one can not help trying to picture to himself just how the ore came into its present position. In the processes of magmatic differentiation, as one ordinarily thinks of them, there is a gradual localization of certain constituents of the magma until a product is produced characterized by the predominance of those constituents. With increasing distance from such a differentiated mass, those constituents should more and more decrease and the remaining constituents increase in quantity until the average composition of the magma is again obtained. This change may take place rapidly, or it may take place slowly. One has the feeling, however, that such a transition should exist. In looking at these exposures no such picture is suggested. If a differentiation has taken place, it has been complete. One can put his finger on almost any point along the contact and say this is ore or this is anorthosite. It is difficult to get away from the suggestion that the ore has been injected into the anorthosite. Yet the irregular form of some of the ore bodies, and the numerous stringers running through the anorthosite in all directions present difficulties to explain. To have afforded passages for such irregular injections, the anorthosite must have undergone a certain amount of crushing and shattering.

That view would place the time of ore injection sufficiently later than the intrusion of the anorthosite to have enabled the latter to solidify and then be subjected to a certain amount of metamorphism. But even such a conception does not seem in accord with the phenomena observed. One would then expect to find somewhat angular and ragged boundaries, whereas the details of the boundaries are smooth and rounded. The only conclusion that is at all satisfying is that the ore came into its present position while the anorthosite was still in a viscous condition. Differentiation of the magma took place, producing a very feldspathic rock and a very pure iron ore. Compared with the degree of differentiation in the case of the ores in the gabbro, it was remarkably complete. The suggestion of Kemp that it was due to the lack of magnesium seems a very plausible explanation, as certain it is, not only here but elsewhere, that the iron ores in anorthosite are uniformly of higher grade than those in gabbro. It would seem that a gabbroitic magma poor in magnesia can differentiate to a greater degree than one rich in magnesia. The differentiated iron mass thus produced instead of solidifying completely in situ, was squeezed, at least in part, into other parts of the still fluid anorthosite. The relations at the contact are what one would expect if such were the processes involved. This is offered merely as a plausible explanation of the phenomena observed in this vicinity. Unfortunately the contacts of the larger ore body on Sanford Hill are not exposed, so that no comparisons can be made between the two areas. The intrusive character of the titaniferous magnetite in the anorthosite of Iron Mountain and Shanton ranch, Wyoming, is beyond question. A study of the relation at the contact of ore and wall rock of the Canadian and other foreign occurrences of titaniferous magnetite in anorthosite would be of considerable interest and scientific importance.

Opposite the Millpond pit and west of the bend in the river is a large area which has recently been prospected by trenching and diamond drilling. Ore has been shown to exist in a nearly continuous body over an area the boundaries of which have not yet been determined. It is not, however, all high-grade coarse ore such as is exposed in the Millpond pit. As stated previously, much of it is fine-grained lean ore resembling the ore found in gabbro. The diamond-drill cores also show the presence of considerable country rock, some of which is basic in appearance.

The ore consists almost entirely of magnetite and ilmenite, with little visible gangue. Here and there are large phenocrysts of green feldspar surrounded by the reaction rims already described. The coarse texture of the ore is distinctive; the grains have a mean diameter of 5 to 10 mm. In this respect the ore resembles the nontitaniferous magnetites of the Adirondacks. The two ores could never be mistaken, however, as the titaniferous has a peculiar mottled luster due to the difference in luster of the magnetite and the ilmenite. The luster, however, is quite different from that of the nontitaniferous magnetites.

In the table of analyses given below, analyses 1 to 6 represent ore from the Millpond pit and are taken from Kemp, with the exception of 6, which was calculated from analyses of concentrates and tailings made by A. C. Fieldner of the Bureau of Mines; analysis 7 represents ore from the "Iron Dam" and is taken from Newland.

Results of analyses of Millpond ore.

Constituent.	1	2	3	4	5	6	7
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	10.73	13.88	19.74	20.24	20.49	18.20	10.85
Fe_3O_4	87.20	82.37	73.62				
SiO_2	1.09	3.67	1.53		.91		1.96
Al_2O_3	.44	1.50	3.50				
Mn_3O_4	.13						
CaO	Trace.	Little.	Little.				
MgO	Trace.	.50	1.60				
P	None.	.017	.037				.008
S	None.	.068	.08				.009
Fe	63.45	59.56	53.62	55.62	54.80	54.47	64.47

The average Fe content of these analyses is 58 per cent and the average TiO_2 content 16.3 per cent. Calculating the TiO_2 in terms of ilmenite and the remaining iron as magnetite, we have as the partial mineralogical composition of the ore 30.97 per cent ilmenite and 64.34 per cent magnetite, a total of 95.21 per cent. This computation brings out clearly the high grade of the ore. Phosphorus is below the Bessemer limit, and sulphur is low.

Metallographic description of ore.—The coarse texture of the ore has already been commented upon. As a result of this texture, there are very few grains below 1 mm. in diameter. The amount of ilmenite is always subordinate to that of magnetite, and varies from less than one-tenth to about one-third. Plate II, *B*, shows the usual relations between the magnetite and the ilmenite grains. The plate shows an etched polished surface of the ore free from visible gangue minerals.

The ilmenite intergrowths in the magnetite show considerable variety, though on the whole they are not very abundant. The magnetite usually etches to a dull black. The gray mottled effects, which in several cases have been shown to be due to the magnetite swarming with irregular particles of ilmenite, are not abundant. This is as one would expect in a coarse-grained ore, as the crystallization must have been slow enough to have given an opportunity to such inclusions to take on definite shapes and orientation.

One of the commonest forms of inclusions shows on the polished section as dots which are scattered over the surface in varying amounts. In places they occur rather sparsely; elsewhere the surface may be thickly covered with them. Where most abundant, they are usually of minute size. They differ from the swarms of minute particles mentioned in the preceding paragraph in that they have distinct, somewhat circular outlines, whereas the latter have indistinct, hazy outlines. Some of the dots attain considerably larger size and reach a diameter of 0.05 mm. The minute dots in such unusual abundance as to produce a clouded effect are seen in Plate IV, *B*. Interspersed among these are also some of the larger sized dots.

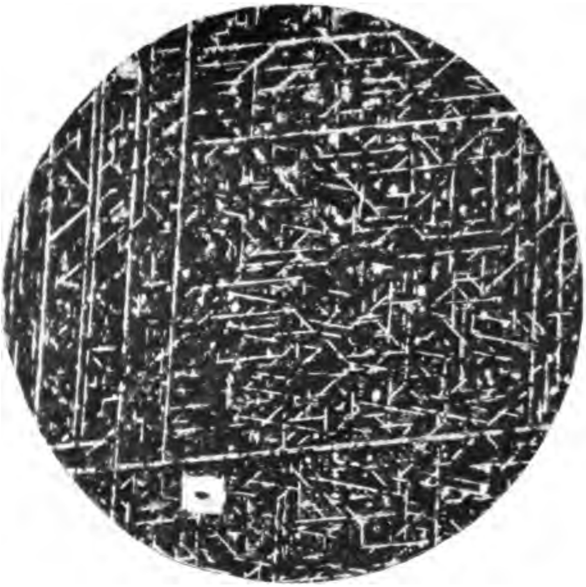
Less abundant, yet prominent, are the tabular intergrowths. More commonly the individual lamellæ are rather short, and where a number occur in the same plane the polished section shows a broken line. The lamellæ may occur isolated, and in such cases often become thicker in proportion to their length than the average. When abundant they take on the regular parallel rectilinear arrangement, producing a one-line, two-line, or three-line intersecting pattern according to the orientation of the section. This broken-line pattern is shown in Plate IV, *B*. The lamellæ are not, however, always short, but attain a length of 1 to 2 mm. and even more in places, producing a continuous-line pattern. Plate VI, *A*, shows a number of these larger lamellæ. The section is also of considerable interest in that it shows the magnetite to be twinned. If examined closely, it will be seen that instead of three series of intersecting lines corresponding to the octahedral cleavage of magnetite there are five series. They correspond to the cleavage of a twin about the octahedral face, and are either four or five in number according to the orientation of the section.

Another feature of many of the sections is the occurrence of a narrow rim of ilmenite about the outlines of the magnetite grains. This phenomenon was already noted in the case of the Lincoln Pond ore (Pl. IV, *A*).

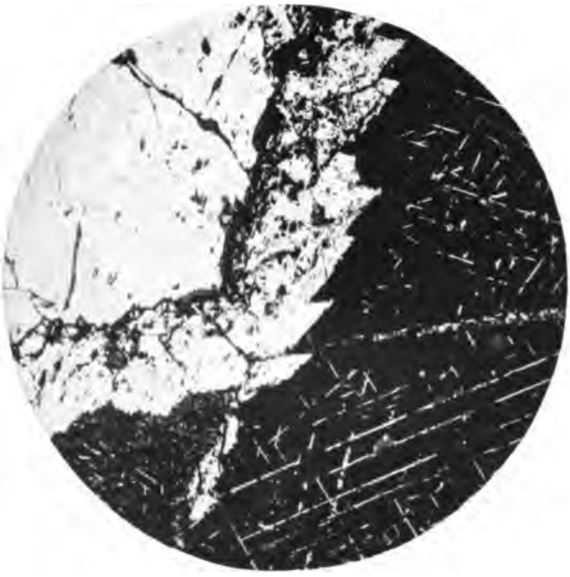
In many places a much coarser form of inclusion than those just described occurs around the ilmenite grains. It is in the form of a zone made up of irregular particles of ilmenite with their longer direction at right angles to the ilmenite border. Locally these particles coalesce, forming a continuous band. There is always a narrow strip of magnetite between the ilmenite grain and this zone. In a few cases the zone completely encircles the ilmenite grain, but usually it is discontinuous. This effect is shown in Plate VI, *B*.

SANFORD HILL ORE.

The Sanford Hill ore is the largest and most important body of titaniferous ore in the Adirondacks. It occurs on the west slope of



A. IRON DAM, N. Y., ORE. (X 60.)



B. IRON DAM, N. Y., ORE. (X 60.)

Sanford Hill overlooking Sanford Lake. Lack of exposures makes impossible the determination of the limits of the ore body. Diamond drilling during the years 1906 and 1907 has demonstrated that the ore continues practically to the lake. Magnetic surveys show lines of attraction that cross the lake and merge with the small ore body on the western shore below Big Island (Pl. V). It may be that the ore continues under the lake to the western shore. On the east, anorthosite is encountered before the summit of the hill is reached, and the summit itself is composed of anorthosite. The lateral extent, parallel to the lake, has not been determined, but is stated by Newland to be at least a half mile. Drilling has proved its continuance in depth to 300 or 400 feet, the maximum depth reached by the drill.

This part of the hill was laid bare at the time the drilling was done preparatory to commencing stripping, and a few trenches were made. Besides these there is an old opening on the hillside with a working face about 30 feet long and 15 feet high.

The anorthosite exposed on the east side of the deposit is very gneissoid. The feldspar is nearly white and running through it are black bands which in thin section are seen to be composed of dark-green hornblende. Smaller particles of the hornblende are scattered through the feldspar. Anorthosite is also scattered within the boundaries of the ore body. It seems to be segregated along certain bands and could easily be sorted in mining so as not to impair the quality of the ore. A thin section of the rock showed a small amount of augite that has to a great extent altered to hornblende.

In the early forties the deposit was prospected with considerable care by Prof. Emmons, for whom a number of pits were made to expose the ore. These pits have since filled up and their exact locations are not known, but the details of the observations are still valuable in that they show the manner in which the ore and the country rock are intercalated. The most detailed of the sections across the ore body made by Prof. Emmons is here reproduced as given by Newland.[a]

Record of the middle transverse section of the Sanford Hill ore body.

Pit No.	Interval.	Remarks.
	Feet.	
1	....	Fine granular feldspar, intermixed with iron, garnet, and hornblende.
2	36	Rich ore breaking into tabular masses.
3	10	Do.
4	15	Rich ore.
5	20	Rich ore, mixed in a small proportion with granular feldspar.
6	12	Granular feldspar in a decomposing state containing only a small proportion of ore.
7	20	Rich ore, mixed with a few scales of black mica and feldspar.
8	22	Rich ore, mixed with garnet and feldspar.
9	24	Nearly the same as No. 8, but brighter.
10	24	Rich ore with a very small proportion of feldspar.

[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908, pp. 159-160.

Record of the middle transverse section of the Sanford Hill ore body—Continued.

Pit No.	Interval.	Remarks.
	Feet.	
11	22	Loose decomposed rock.
12	17	Rich ore.
13	15	Rich ore, with feldspar.
14	39	Rich granular ore, with a resinous luster.
15	15	Lean ore.
16	22	Principally rock.
17	28	Pure ore.
18	35	Do.
19	36	Rich ore.
20	22	Pure ore.
21	27	Do.
22	30	Do.
23	29	Do.
24	30	Ore mixed with garnet.
25	14	Rock mixed with particles of ore.

On the basis of his explorations, Prof. Emmons estimated the ore body to contain 6,830,000 tons, at a depth of 2 feet below the adjoining surface. Besides being a very large deposit, it is well situated for mining, as its topographic position on the side of the hill makes open-quarry methods applicable.

The ore is identical in character with that at the Millpond pit. At the old opening it contains many large phenocrysts of green feldspar, which attain a length of 6 cm. and more. These are always surrounded by a reaction rim in which a golden-brown biotite is a prominent constituent. In thin section the feldspar is clouded by the minute inclusions described in the feldspar at the Millpond pit. Surrounding it is a narrow zone of clear feldspar with larger green inclusions, many of which are spinels. Then comes a broader zone of femic minerals, of which the most abundant are brown mica and hornblende. Less abundant is a nearly colorless augite. Beyond this zone is the magnetite.

In the following table of analyses, analyses 1 to 5 are quoted from Kemp and 6 and 7 from Newland, by whom the original sources are acknowledged. Analysis 8 was calculated from analyses of concentrates and tailings made by A. C. Fieldner of the Bureau of Mines.

Results of analyses of Sanford Hill ore.

Constituent.	1	2	3	4	5	6	7	8
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	10.91	20.03	19.52	18.70	14.52	9.45	14.0	19.02
Fe_3O_4	87.60	70.73	70.80	71.03	....	....	83.4	....
SiO_2	.87	2.46	1.39	1.34	1.39	2.09	....	....
Al_2O_3	.53	3.50	4.00	....	5.81	....	....	....
P	....	....	.022	....	....	.007	....	....
S	....	....	.028	....	....	.027	....	....
Fe	62.65	51.22	51.30	51.44	56.60	63.36	60.5	55.07

In these analyses the average percentage of Fe is 56.52 per cent and of TiO_2 15.77 per cent. Computing the TiO_2 in terms of ilmenite and the remaining iron as magnetite we get 29.96 per cent ilmenite and 62.81 per cent magnetite in the ore, a total of 92.77 per cent. The composition is almost identical with that of the average of the Millpond ore. The two determinations for phosphorus show the content of that element to be below the Bessemer limit; the sulphur content is also low.

Metallographic description of ore.—The microstructure of the Sanford Hill ore is identical with that of the Millpond ore. The same types of intergrowth are found in this ore, and it is therefore useless to repeat the descriptions of them at this point. The only difference, if any, is that the intergrowths of ilmenite in the magnetite are somewhat less abundant in the Sanford Hill ore.

POSSIBILITIES OF UTILIZING THE ORES IN ANORTHOSITE.

The far greater size of the deposits, the much higher iron content, and the coarser texture of the ores in anorthosite make them far more attractive from a commercial standpoint than the ores found in the gabbro. Transportation facilities would have long since been provided if there had been any feeling of certainty that the difficulties caused by the presence of titanium could be overcome. Numerous experiments have been made to separate the titanium from the ore by means of magnetic separation, and the results of some of them are given below.

Kemp [a] gives the following results of analysis of concentrates and tailings of a magnetic separation of the Sanford Hill ore:

Results of magnetic separation of Sanford ore.

Constituent.	Concentrates.	Tailings.
	Per cent.	*Per cent.*
TiO_2	4.00	47.50
Fe	62.66	36.86

No statement is made as to the size to which the ore was crushed nor of the ratio between concentrates and tailings. If we assume the average composition of the Sanford Hill ore as the composition of the sample tested, the ratio of concentrates and tailings can be calculated. On the iron basis the tailings constitute 25.9 per cent of the original ore, and on the titanium basis 27.7 per cent. The agreement is so close that the mean 26.8 per cent may be assumed to be the amount of the tailings.

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[a] Kemp, J. F., The titaniferous iron ores of the Adirondacks: 19th Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 416.

The possibilities of magnetic separation of the Sanford Hill ore are also discussed by Newland,[a] whose statements are next given, as follows:

> A partial separation of the magnetite and ilmenite was obtained with the ore from the Sanford pit at Lake Sanford. A sample was crushed through a 40-mesh sieve and the magnetite removed with a small hand magnet. The results from chemical analysis of the crude ore (1), magnetite concentrate (2), and the ilmenite and other residual minerals (3) are given herewith. The analyses were made by E. W. Morley.
>
> *Results of analyses of Sanford pit ore.*
>
> | Constituent. | 1 | 2 | 3 |
> |---|---|---|---|
> | | *Per cent.* | *Per cent.* | *Per cent.* |
> | Fe_2O_3 | 55.9 | 54.39 | 14.28 |
> | FeO | 27.5 | 28.66 | 30.93 |
> | TiO_2 | 14 | 8.93 | 45.23 |
>
> It will be observed that the magnetite concentrate still contains a considerable proportion of titanium, mostly due, no doubt, to the inclusion of particles of mixed character. By crushing still finer a cleaner separation may be made, as has been demonstrated * * *. The analyses are not reducible to simple terms of magnetite and ilmenite, and further work is needed before the chemical relations can be fully stated. It is quite likely that the magnetite itself carries a proportion of the titanium, in which case the entire removal of the latter would be impossible.
>
> Another feature which may promote the use of the ores from that locality is their amenability to concentration, whereby the titanium can be reduced by at least a third of the total or to less than 6 per cent probably as a maximum limit. To the courtesy of F. E. Bachman, general manager of the Northern Iron Co., the writer is indebted for information concerning an experimental run made upon Lake Sanford ores at the Mineville magnetic concentrating plant within the past year. A 40-ton sample was passed through one of the mills and the concentrates showed the following percentages: Fe, 60.60 per cent; TiO_2, 9.66 per cent (equivalent to 5.8 per cent Ti). The tailings from the treatment gave: Fe, 42.84 per cent; TiO_2, 32.22 per cent. A sample of the concentrates recrushed so as to pass through a 16-mesh screen and reconcentrated by hand showed the following percentages on analysis:
>
> | | |
> |---|---|
> | Fe | 63 |
> | SiO_2 | 1.08 |
> | TiO_2 | 5.25 |
> | Al_2O_3 | 5.65 |
>
> Another sample was crushed through a 40-mesh screen and subjected to separation under water with a hand magnet. Analyses of the concentrates are given below. No. 1 is by A. S. McCreath & Son and No. 2 by P. W. Shimer.
>
> *Results of two analyses of Lake Sanford ore.*
>
> | Constituent. | 1 | 2 |
> |---|---|---|
> | | *Per cent.* | *Per cent.* |
> | Fe | 65.35 | 64.69 |
> | Mn | .186 | .... |
> | SiO_2 | .14 | .... |
> | TiO_2 | 5.32 | 6.49 |
> | Al_2O_3 | 2.76 | 2.59 |
> | CaO | .05 | .... |
> | MgO | .76 | .... |
> | P | .012 | .0045 |
> | S | .041 | .... |

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[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: N. Y. State Mus. Bull. 119, pt. 3, 1908. pp. 152, 154-155.

While it would scarcely be practicable, perhaps, to crush the ore to a size that would permit a reduction of the titanium to the limits indicated in the last analyses, there would appear to be no difficulty in the way of preparing concentrates with an average of 8 or 10 per cent TiO_2. The loss of iron in the tailings is the only drawback to concentration, but in the case of immense deposits like those at Lake Sanford, which can be worked very cheaply, this could hardly be critical.

In none of the above cases is the ratio of tailings to concentrates given. In the case of the 40-ton sample, however, a ratio can be calculated by again assuming the original ore to have had the average composition of the Sanford ore, an assumption that, in view of the large quantity used, is fair. On the iron basis the tailings constituted 23 per cent of the original ore and on the titanium basis 27 per cent. The mean of these, 25 per cent, should be nearly correct.

Two separations made by the author, one on Sanford Hill ore and one on Millpond ore, did not give results as favorable as those above. The analyses of the tailings and concentrates were made by A. C. Fieldner, of the Bureau of Mines. The results follow:

Results of magnetic separation of Sanford Hill ore.

	Unscreened ore.	Ore through 50-mesh, over 100-mesh.[a]		Ore through screen finer than 100-mesh.[b]
		Magnetic.	Non-magnetic.	Magnetic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity	....	78.2	21.8	75.9
Fe	55.07	61.23	32.99	61.23
TiO_2	19.02	11.15	47.20	10.47

[a] 47 per cent. [b] 53 per cent.

Results of magnetic separation of Millpond ore.

	Unscreened ore.	Ore through 50-mesh, over 100-mesh.		Ore through screen finer than 100-mesh.
		Magnetic.	Non-magnetic.	Magnetic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity	....	83.2	16.8	85.3
Fe	54.47	58.89	32.74	59.17
TiO_2	18.20	13.18	43.03	12.28

A sample was also prepared from the Sanford Hill ore by picking small pieces of magnetite from the surface of etched polished sections. As far as possible only such pieces were taken as were free from all visible intergrowths of ilmenite. The sample was further tested with a magnet to make sure that it contained no nonmagnetic particles. The analysis of this sample made by A. C. Fieldner is as follows:

Fe	61.04
TiO_2	11.00

From the manner in which this sample was prepared, the analysis results given ought to represent the most favorable results obtainable.

In the first two separations made by the writer the percentage of titanium was reduced by 41.4 and 27.6 per cent, respectively. If we assume in the third case the average composition of the Sanford Hill ore, the reduction was 30.3 per cent. The average of the three is 31.1 per cent, which accords with Newland's estimate that the titanium content can be reduced by a third.

The result obtained in the test at the Mineville magnetic-concentrating plant represents, therefore, the maximum separation obtainable; and the average of a long run of the ores is not likely to fall far behind this. A conservative statement of the results obtainable by magnetic separation is that concentrates can be produced running about 60 per cent Fe, less than 7 per cent Ti, low in sulphur, and far below the Bessemer limit in phosphorus, with a loss of not more than 25 per cent in the tailings. Aside from the titanium content, this is a most desirable product for the blast furnace. By mixing these concentrates with other ores in a ratio between 1 to 2 and 1 to 3, the titanium content can be brought down to 2 per cent, a quantity that would cause no trouble in the furnace. The size and situation of the deposit with reference to easy mining methods are such that, with transportation facilities provided, the concentrates could profitably be put on the market at the current prices. Of course the prejudice against titaniferous ores would retard and probably make impossible the sale of the ores if put on the market by an independent operator. There is no reason, however, why the deposits should not be worked by interests that control their own furnaces, and it is doubtless a question of only a few years before mining will have been begun on these ores.

NEW JERSEY.

Magnetite ores occur throughout the pre-Cambrian rocks of the New Jersey Highlands. Many of these ores contain a small amount of titanium, but in only a few instances does the percentage of titanium become as high as that usually contained in titaniferous magnetites. Furthermore, the occurrences with high titanium content are among the smaller deposits of the region, and will never be a factor in the utilization of such ores. The region was not visited for that reason; but because frequent mention is made in the literature of the titanium content of the New Jersey ores a brief account of the deposits will be given.

Practically all of the information available in regard to these ores has been included in the report on "Iron Mines and Mining in New Jersey," by W. S. Bayley,[a] in which reference is made to the original sources.

FIELD RELATIONS OF REGION.

The pre-Cambrian rocks of New Jersey consist of gneisses, pegmatites, and a series of sedimentary rocks called the Franklin formation, of which the most important member is a white crystalline limestone. These pre-Cambrian rocks form a series of ridges trending northeast, separated from one another by intervening valleys of Paleozoic rocks, and having a general southeast dip. Corresponding to the principal belts or ridges, the magnetites have been grouped into four belts, known from southeast to northwest as the Ramapo, the Passaic, the Musconetcong, and the Pequest. Magnetic iron ore occurs in all of the pre-Cambrian rocks, but the titaniferous ores are confined to the gneisses. The gneisses consist of alternations of potash rich, soda rich, and iron and magnesium rich rocks, called, respectively, the Byram gneiss, the Losee gneiss, and the Pochuck gneiss.

The origin of the gneisses is rather problematical, as they have been subjected to intense regional metamorphism. Wolff[b] made a microscopic study of the gneisses at Hibernia and favors an origin by metamorphism of sediments. Westgate,[c] who studied the rocks on Jenny Jump Mountain, is in doubt about the light-colored feldspathic gneisses, but favors an igneous origin for the dark hornblendic varieties. Bayley[d] compares an analysis of a specimen of the hornblendic variety with an analysis of an Adirondack norite, and finds them chemically almost identical. Hence, though there is evidence pointing to the existence of metamorphosed gabbroitic rocks, the relation of the titaniferous ores to such rocks is not yet made clear. The titaniferous ores all occur within the areas mapped as acid gneisses, and not within the areas of the Pochuck gneiss. It seems, however, that intercalations of Pochuck gneiss too small to map occur in the acid gneisses, as the presence of such is mentioned at the Richard mine, though none is indicated on the map at that point. In other cases the character of the gneiss is not made clear.

Direct evidence that any of these ores are magmatic segregations in gabbros that have been subsequently metamorphosed is lacking. The very low titanium content of nearly all of the ores, with every gradation down to ores practically free from titanium, compared to the uniformly high titanium content of magmatic segregations of titaniferous magnetites must be of some significance. It has long been believed, and the belief is founded on experience, that only magnetites segregated in gabbroitic rocks are titaniferous, or carry more than a very small amount of titanium; and when analyses of some of these New Jersey ores were found to run high in titanium it was only natural to try to connect those ores with rocks of that character. A notable exception to such a rule is the contact-metamorphic titaniferous magnetite on the Cebolla Creek in Gunnison County, Colo.[a] It is true that the source of the ore on the Cebolla is a basic rock, nevertheless the method of origin was pneumatolytic, showing that considerable titanium can be carried away from the magma by pneumatolytic processes. A review of the theory of origin advanced by Bayley to account for the New Jersey magnetites is beyond the scope of this report, and for the present purpose it is characterized as of combined magmatic and pneumatolytic, or hydato-pneumatolytic, origin. The gneisses are regarded as of igneous origin. After their intrusion and partial cooling ferruginous portions of the same magma were intruded into them. These intrusions were subsequently enriched from the same source by iron-bearing solutions or vapors, which "made the ore lenses that now comprise the ore bodies." Bayley makes no exception of the titanium-bearing deposits, and it seems very probable that they belong to this class, and not to the true "titaniferous magnetites" discussed in this report.

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[a] Vol. 7 of the final-report series of the State geologist, 1910.

[b] Wolff, J. E., Geological structure in vicinity of Hibernia, N. J., and its relation to the ore deposits: Ann. Rept. of State Geologist of New Jersey, 1893, pp. 359-369.

[c] Westgate, L. G., The geology of the northern part of Jenny Jump Mountain, Warren County: Ann. Rept. of State Geologist of New Jersey, 1895, pp. 21-61.

[d] Op. cit., p. 123.

It is quite probable that a few of the high titanium occurrences may be exceptions and do occur in metamorphosed gabbros. Thus the Church or Van Syckle mine in Hunterdon County shows in a series of analyses a TiO_2 content averaging about 12 per cent, which is well within the limits of such ores.

THE TITANIUM-BEARING ORES.

The table following gives the analyses of those magnetites that contain more than 1 per cent TiO_2. They are derived from various sources, but are compiled in a series of tables in Bayley's report, the original source being given in each case.

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[a] See p. 138.

Results of analyses of New Jersey ores.

Name of mine.	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	H_2O.	TiO_2.	P_2O_5.	S.	Cr_2O_3.	MnO.	V_2O_3.	Insol.	Total.	Fe.
Barker										1.47	Trace.	0.00		0.00				61.94
Bayard										6.00	Trace.							49.50
Beers										7.83	0.09	.31		.00				54.46
Bishop										1.98	.21	.39		.00				65.87
Bloom										4.77	Trace.	Trace.						37.5
Cannon [a]										2.77	Trace.							63.53
Charlotteburgh										1.02	Trace.	.39						64.94
Cramer I										9.95	.32	.00		Trace.				62.23
Cramer II										4.27	.90	(?)		Trace.				40.25
Day										5.08	.19	Trace.		.46				50.88
DeKay										4.68	.25	.41						45.75
Elizabeth [b]	1.38	0.55	65.26	30.20	0.10	0.68	Trace.	Trace.	0.12	1.09	.49	.01		.03	0.08		99.99	69.24
Do. [c]	8.46	.77	56.18	27.81	1.88	1.68	0.22	0.36	.28	1.06	.98	.01	0.00	.04	.11		99.84	61.02
Hager										1.40	.67	7.59		.00				56.13
Do. [d]										7.13	.44							56.39
Haggerty										4.27	.76	.05						58.55
Hann										1.07	.84	.09		.00				56.97
Hibernia [b]	12.08	1.63	56.21	26.39	.88	1.08	.17	.15	.17	1.21	.02	.03	Some.	.07	.21			59.93
Do. [c]	7.14	1.23	60.89	25.94	1.40	1.31	.08	.13	.25	1.25	.53	.01	.00	.03	.15			62.85
Holt Farm	18.90	12.48	65.52		.86	4.45				1.30	.06	1.23		.55				47.44
Horton	16.15	3.34	68.48		1.94	4.87				1.09	3.01						99.28	49.58
Hurd [b]	1.51	.37	64.87	31.11	.40	.51	Trace.			1.05	.05	.01	.00	.08	.13		100.33	69.69
Do. [c]	6.37	1.59	57.46	27.23	1.01	2.93	.12			.70	2.18	.05	.00	.03	.08		100.14	61.46
Jackson	9.80	9.48	73.15		.72	1.46				4.40	.54	.06					99.61	52.96
Kahart										1.42	.39	1.23						52.34
Keeler		1.17	75.95		Trace.	4.03				1.44	3.39	.01		.25		12.60	98.84	54.89
Leonard [b]	3.56	.44	61.47	55.24	1.68	1.66	.10			1.15	.54	.02	.00	.03	.08		100.05	65.88
Do. [c]	7.62	.49	29.04	26.12	1.89	4.34	.27			1.05	2.44	.02	.00	.04	.08		100.01	59.04
Marsh										2.08	.38	.06		.00				57.62
Martin										1.02	.58	.00						49.25
Naughright [e]			82.78		.91	2.70				6.40	2.56	.41				2.40	97.79	59.93
Do. [f]										7.62	.16	.27						64.77
Old Blue		.66	93.10		.43					1.95	.06					4.10	100.30	67.40
Richard [b] [g]	1.31	.73	64.01	30.62	.33	.96	Trace.	Trace.	.10	1.29	.56	.12	.00	.05	.10		100.18	68.69
Richard [e]	3.77	.79	61.16	29.56	.64	1.23	.12	.14	.16	1.30	.45	.01	.00	.06	.10		99.48	65.87
Do. [c]	8.48	.86	55.99	26.98	1.89	2.42	.33	.19	.15	1.01	1.54	.01	.00	.02	.08		99.95	60.34
Shafer										5.03	.21	.03		Trace.				45.22
Stockholm										3.65	Trace.	.61		4.86				67.10
Stony Brook										1.52	Trace.	.00		.00				64.69
Van Syckle	5.40	9.29	69.34		3.35	.39				11.60	Trace.	1.21		.00				50.20

[a] Three other analyses showed less than 1 per cent TiO_2.

[b] Selected sample. Tests for NiO, CoO, BaO, and SrO showed the absence of these constituents.

[c] Average sample. Tests for NiO, CoO, BaO, and SrO showed the absence of these constituents.

[d] Other analyses show 4.15 and 5.73 per cent of TiO_2.

[e] Gray ore.

[f] Blue ore.

[g] Another sample contained 0.30 per cent of TiO_2.

Bayley's report also includes 13 complete analyses of the ores in which V_2O_3 has been determined. These are of interest in comparison with the relation between the ratio of TiO_2 to V_2O_5 in certain Canadian ores and Adirondack ores as developed by Pope.[a] Pope found that a number of nontitaniferous magnetites which he tested were free of vanadium, whereas the titaniferous magnetites always showed some vanadium. Moreover, the ratio of vanadic oxide (V_2O_5) to titanic oxide (TiO_2) in the titaniferous magnetites from eastern Ontario and the Adirondacks was always in the neighborhood of 1 to 28. Consequently he suggested that in the titaniferous magnetites these two elements, vanadium and titanium, may be related to each other in a manner analogous to the relation of the oxides in definite ratios in the complex inorganic oxides studied by Gibbs, Marignac, and others.

The following table gives the percentages of TiO_2 and V_2O_3 determined in the New Jersey ores, and the ratio of TiO_2 to V_2O_5 calculated from them:

Vanadic oxide and titanic oxide in the New Jersey ores.

Mine.	TiO_2.	V_2O_3.	TiO_2 + V_2O_5.
	Per cent.	*Per cent.*	*Per cent.*
Hibernia	0.54	0.14	3.2
Richard	1.29	.10	10.7
Do	.30	.11	2.3
Do	1.30	.095	11.3
Do	1.01	.08	10.4
Hibernia	1.21	.21	4.7
Do	1.25	.15	6.9
Leonard	1.15	.08	11.9
Do	1.05	.08	10.18
Elizabeth	1.09	.08	11.2
Do	1.06	.11	8.0
Hurd	1.05	.13	6.7
Do	.70	.08	7.2

It is apparent from the table that not only is the proportion of vanadic oxide compared to the titanic oxide much greater in the New Jersey ores than in the ores studied by Pope, but also there is a wide variation from constancy in the ratio. The New Jersey ores can not be regarded as a fair test of the ratio, however, for, as already pointed out, they do not belong to the true "titaniferous magnetites." On the other hand, if they are thrown out of the class of titaniferous magnetites, the analyses would indicate that a vanadium content is not characteristic of the titaniferous ores alone.

NORTH CAROLINA.

Titaniferous magnetites occur at a number of localities in the Piedmont and Appalachian regions of North Carolina, but no deposits of great promise are known. The rocks of this western half of the

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[a] Pope, F. J., Investigation of magnetic iron ores from eastern Ontario: Trans. Am. Inst. Min. Eng., vol. 29, 1899, pp. 395–397.

State consist principally of a complex of gneisses, ranging from acidic or granitic gneisses to very basic rocks, as hornblende gneisses, granites, and other igneous rocks. The most recent and complete account of the titaniferous magnetites occurring in this region is contained in the bulletin on the iron ores of the State by Nitze.[a] This report includes all information in previous reports of the State survey, and, except for data relative to the localities visited by the author of this report, it forms the basis of the following account.

As most of the localities cited in the North Carolina reports show no evidence of the existence of deposits of any importance, it was considered useless to attempt to visit all, and at the suggestion of Dr. J. H. Pratt, State geologist of North Carolina, the author visited what were considered the two most promising areas, the belt extending across Rockingham, Guilford, and Davidson Counties, just west of Greensboro, and the area to the north of Lenoir, in Caldwell County.

The general distribution and character of the ores is very briefly indicated; a more detailed description is given only of the two areas visited by the writer.

DISTRIBUTION AND CHARACTER OF THE ORES.

References to the character of the immediate country rock of the ores are very meager and of a most general nature. All that can be gotten from the literature is that it is in most cases a schistose femic rock. No information as to what the original rock might have been is given. Little can be said, therefore, in regard to the geology of the ores.

Our knowledge of the character and extent of the ores is more complete, as a large number of analyses have been made, and some data are given indicating the size of the ore bodies. The table following gives the available analyses, arranged alphabetically by counties. It is the same as that given by Nitze,[b] with five analyses added in Guilford County taken from Lesley.[c]

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[a] Nitze, H. B. C., A preliminary report on the iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 1893.

[b] Op. cit., pp. 229-231.

[c] Lesley, J. P., Notes on the titaniferous iron belt near Greensboro, North Carolina: Proc. Am. Phil. Soc., vol. 12, 1871, pp. 154-156.

Results of analyses of North Carolina ores.

Source of ore.	SiO$_2$.	Fe.	Mn.	S.	P.	TiO$_2$.	Cr$_2$O$_3$.	Al$_2$O$_3$.	CaCO$_3$.	MgCO$_3$.	CaO.	MgO.
ALLEGHANY COUNTY.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1. Fielden Carrico, Old Forge workings	6.20	54.72		0.038	0.047	4.86						
ASHE COUNTY.												
2. Cicero Pennington, Wallens Creek	4.75	52.23		.112	.021	8.91	1.19					
3. Cicero Pennington, Wallens Creek	4.72	52.44		.077	.004	5.38						
4. Cicero Pennington, Wallens Creek	5.07	52.45			.022	9.11						
5. Bauguess opening, near Little Helton Creek	6.35	57.66		.061	.008	4.69	.505					
6. Bauguess opening, near Little Helton Creek	7.91	53.35		.078	.022	4.92						
7. G. C. McCarter, Little Helton Creek	9.90	46.81		.137	.025	6.03	.63					
8. G. C. McCarter, Little Helton Creek	10.92	40.71		.065	.012	5.54						
9. G. C. McCarter, Shipps Branch opening	5.37	51.75			.018	9.17						
10. William Young, Little Helton Creek	5.12	50.77		.04	.005	4.95						
11. William Young, Little Helton Creek	4.35	52.85			.013	8.80						
CALDWELL COUNTY.												
12. J. K. Farthing, Warrior Creek	6.50	31.92	0.39	.058	.025	2.40			7.48	15.64		
13. Joshua Curtis, Yadkin River (average)	6.63	36.00	1.09	.021	.060	14.90			7.37	16.08		
14. Joshua Curtis, Yadkin River (selected)	7.55	28.24		.013	.140	41.21						
15. Joshua Curtis, Yadkin River		37.10			Trace.	36.40						
16. Joshua Curtis, Yadkin River		25.76			.076	38.81						
CATAWBA COUNTY.												
17. Forney ore bank, near Maiden Station	1.41	67.92		.07	.025	1.60						
DAVIDSON COUNTY.												
18. K. R. Swain, massive ore	.76	57.68				13.52	.46	1.68				
19. K. R. Swain, micaceous ore	5.68	52.68				11.67	.48	5.08				
DAVIE COUNTY.												
20. Kelley-Lefler place, 5 miles south of Mocksville	.778	60.00		.033	.008	10.32						
21. Allen place, 7 miles northeast of Mocksville	5.50	52.80		.11	.02	8.00						
GUILFORD COUNTY.												
22. Elisha Charles	.40	59.03				11.95	1.07	1.06				
23. Widow Cook	1.84	56.21				13.28	.65	2.30				
24. John Clark	1.30	56.41				12.35	1.10	2.54				
25. Sargeant shaft	1.31	55.06				13.60	.72	4.26				
26. Sargeant shaft		53.20			.005	Present.						

27. Sargeant shaft	12.86	53.27	....	....	....	13.58	....	....	....	....	....	....
28. Mrs. McCuiston, soft micaceous	....	43.47	....	....	....	16.06	....	....	....	....	....	....
29. Mrs. McCuiston, soft micaceous	12.75	41.95	....	....	....	15.35	1.25	5.17	....	....	....	....
30. Mrs. McCuiston, magnetic part of above	1.30	67.60	....	....	....	1.27	1.43	.55	....	....	....	....
31. Mrs. McCuiston, nonmagnetic part of above	26.80	21.63	....	....	....	16.20	.43	8.87	....	....	....	....
32. Mrs. McCuiston, massive ore	....	33.97	....	....	....	2.63	....	....	....	....	....	....
33. W. A. Lewis	.50	57.32	....	....	....	12.27	.57	3.62	....	....	....	....
34. Belt west of Greensboro [a]	.75	57.77	.22	....	....	12.08	.32	4.62	....	....	0.13	2.04
35. Belt west of Greensboro	1.89	59.95	.32	....	....	8.72	.40	3.93	....	....	.17	1.36
36. Belt west of Greensboro	1.04	58.52	Trace.	Trace.	.00	12.32	Trace.	3.87	....	....	.64	.49
37. Belt west of Greensboro	1.50	60.41	.08	.00	Trace.	8.65	.83	2.90	....	....	.75	2.02
38. Belt west of Greensboro	.52	57.30	.48	.00	.00	13.74	Trace.	4.50	....	....	.72	.54
LINCOLN COUNTY.												
39. Lawson Bess, Indian Creek	11.37	56.95	....	.045	.029	2.40	....	....	....	....	....	....
MACON COUNTY.												
40. Felix Kilpatrick, 5 miles east of Franklin	.77	54.24	....	.04	.013	17.60	....	....	....	....	....	....
41. Alex. Waldroop, 6 miles west of Franklin	11.91	20.64	.69	.089	.016	3.20	....	....	3.31	14.69	....	....
MADISON COUNTY.												
42. Road, midway between Asheville and Burnsville	.83	36.26	.63	.09	Trace.	37.88	....	9.51	....	....	....	....
43. John Brigman, Paint Fork					Titanic acid present in large quantity.							
44. Swan Woody, Spring Creek	2.37	62.16	....	.026	.014	7.44	....	....	....	....	....	....
MITCHELL COUNTY.												
45. Avery land, Roaring Creek, Yellow Mountain	1.46	65.32	....	.025	.009	4.80	....	....	....	....	....	....
46. Avery land, Roaring Creek, Yellow Mountain	.54	66.95	....	None.	.015	6.80	....	....	....	....	....	....
47. Parker place, 2 miles west of Burnsville	1.22	57.98	....	.015	.041	4.56	....	....	....	....	....	....
48. Joel Gouge, mouth of Little Rock Creek	1.13	64.56	....	.027	.078	4.48	....	....	....	....	....	....
49. Above Jenkins mine, Greasy Creek	6.58	54.48	....	.023	.033	4.96	....	....	....	....	....	....
ROCKINGHAM COUNTY.												
50. Levi Shaw	1.80	54.17	.96	....	....	14.46	.97	2.66	....	....	....	....
51. P. Hopkins	.74	55.61	.82	....	....	13.92	1.07	3.82	....	....	....	....
52. Granular reddish ore	1.39	30.97	.63	....	....	.78	.30	52.24	....	....	....	....
53. Granular grayish ore	.98	33.52	.80	....	....	2.42	Trace.	44.86	....	....	....	....
54. Dannemora mine	4.71	48.41	....	.089	.023	13.74	.34	8.68	....	....	....	....
55. Dannemora mine, fine ore	....	49.41	Trace.	....	.001	Present.	....	....	....	....	....	....
YANCEY COUNTY.												
56. Mine Fork, 6 miles north of Burnsville	9.25	39.42	....	.12	.011	11.90	....	....	....	....	....	....
57. Jerry Ferguson, 9 miles west of Burnsville	23.38	39.00	....	....	....	2.56	....	....	....	....	....	....

[a] Ore represented by this analysis had a trace of V_2O_5.

These analyses show a considerable range in TiO_2 content; whereas a number carry only a small percentage of TiO_2, others have such a high percentage that the ore must consist almost entirely of ilmenite. The phosphorus ratio in nearly all of the ores is below the Bessemer limit, and sulphur is low. The percentage of iron is also high in most of the analyses. Except for their titanium content, most of the ores would be classed as medium to high grade.

ALLEGHANY COUNTY.

A zone of hornblende schists, in many places altered to steatite or soapstone, and carrying crystalline grains of magnetite, usually titaniferous, extends across Alleghany County parallel to the Little River and usually on the south side of it. Locally the magnetite becomes more abundant in the schists and may be sufficiently concentrated to form small lenses of ore. On the farm of Fielden Carrico, near the State line, several such ore bodies were opened up about 30 years ago to supply a near-by forge in Virginia (see analysis 1). These openings have long since been abandoned and caved in.

ASHE COUNTY.

A belt of titaniferous magnetite extends in a northeasterly direction from Helton Creek near Sturgill to Little Helton Creek, a distance of 2½ miles. The analyses of the ores in this belt (analyses 2 to 10) show a moderate titanium content.

At the northeast end of the belt is a series of outcrops, one of which shows an ore bed at least 25 feet wide. It is a coarse granular magnetite practically free from gangue. The country rock is in part a prophyllite schist and in part a hornblende rock altering to asbestos. South of these outcrops is another showing 5 feet of ore with a gangue of epidote, feldspar, and quartz. At the southwest end of the belt are several more outcrops, in which the width of the ore ranges from 8 to 15 feet. The ore is a fine-grained magnetite with a gangue of hornblende and epidote.

CALDWELL COUNTY.

Two localities in this county were visited by the writer, but neither showed either large or promising deposits.

RICHLANDS COVE DEPOSIT.

Sixteen miles north of Lenoir in what is known as the Richlands cove is a body of titaniferous iron ore on the east bank of the Yadkin River. A small opening has been made adjacent to the river bank exposing a face about 20 feet high and 40 feet wide. This titaniferous mass occurs within a country rock consisting of sericitic schist. It consists of small particles of ore in a matrix chiefly made up of fibrous and scaly aggregates of chlorite, serpentine, and talc. The individual ore particles average less than one-half mm. in diameter, and rarely exceed 1 mm. They are very slightly magnetic to nonmagnetic. Two polished sections of the ore etched with hydrochloric acid retained their luster and showed no evidence of the intergrowths of ilmenite and magnetite. These facts, together with the high titanium content shown in the analyses in the table (analyses 13 to 16), indicate that the ore particles consist chiefly of ilmenite. This is further borne out by the fact that the sands along the river close to the deposits contain only nonmagnetic ore particles.

Just north of the opening on the river bank is a small side valley in which a rock of identical character outcrops. This outcrop is about 300 feet from the river on the north side of the valley.

Neither of these deposits shows extensive outcrops, and they seem to be only small intercalations in the more acidic country rock. They undoubtedly represent small basic intrusions that have undergone metamorphism with the rest of the region.

The titanium content is so high that the deposits can not be regarded as iron ores. As sources of titanium, their inaccessible location and seeming small size are great drawbacks. At present they possess no economic value.

FARTHING DEPOSIT.

On the north side of Warrior Creek, 5½ miles north of Lenoir, there are outcrops of an ore-bearing rock. The rock consists principally of a green hornblende schist carrying considerable ore disseminated in minute grains and in stringers of nearly pure ore. It occurs as an intercalation in more acidic schistose rocks. Similar rock can be traced for some distance to the southwest by means of surface fragments, but no openings have been made on this occurrence.

Locally this hornblende rock contains richer portions of fine-grained ore. A thin section of such a piece consisted principally of the ore minerals and spinel. Less abundant were augite and hornblende. The ore grains are less than 0.5 mm. in diameter, and do not constitute more than one-third of the mass. On etching polished surfaces of these ores, the small magnetite grains are dissolved out without showing any ilmenite intergrowths, and the polished surfaces of the ilmenite remain unattacked. Further evidence that the small pits on the polished surface were occupied by magnetite is the fact that a considerable part of the powdered ore is magnetic. Analysis 12 shows the composition of the ore.

Adequate exposures to enable one to judge accurately the extent of the occurrence are lacking. The richer parts of the rock are so lean, however, as to preclude any possibility of working the deposit.

CATAWBA COUNTY.

A belt of titaniferous ore extends across parts of Catawba and Lincoln Counties, from a point southwest of Newton to about 9 miles west of Lincolnton. At the northeast end is the Forney mine, which formerly supplied several forges in the neighborhood. The ore is a coarse granular magnetite, usually free from gangue, and occurs in irregular pockets a few inches to 3 or 4 feet in thickness. The country rock is called syenite in the North Carolina report. An analysis of the ore (analysis 17) shows a low titanium content. Float ore found in this belt at the southwest end also shows (analysis 39) only a small percentage of titanium.

DAVIDSON COUNTY.

See Guilford County.

DAVIE COUNTY.

Titaniferous ores are described at two points in Davie County near Mocksville.

About 5 miles south of Mocksville, near the mouth of Bear Creek, is a fair showing of float ore for a distance of 600 feet on the old Maxwell place. Float ore can be traced at intervals for 1½ miles to the southwest to the South Yadkin River. The country rock is described as "hornblende and syenite, with occasional dissemination of magnetite granules." The ore is a medium grain magnetite with little gangue (analysis 20).

Similar ore occurs 7 miles northeast of Mocksville and 1 mile east of Kernatzer station. Several pits and a shaft were put down here during the Civil War. The ore was worked in a forge 4 miles distant on Dutchmen's Creek. Float ore can be traced faintly 200 to 300 yards northeast and southwest of the old shaft (analysis 21).

GUILFORD COUNTY.

A belt of titaniferous magnetite extends across Guilford County in a northeasterly direction, and passes beyond the boundaries of Guilford County into Rockingham County on the northeast and into Davidson County on the southwest. It lies to the north and west of Greensboro. It consists of two parallel subordinate belts known, respectively, as the Tuscarora belt and the Shaw belt, the total length of which is 30 miles. The longer and more persistent is the Tuscarora belt. The Shaw belt lies several miles northwest of it.

The area is one of prevailing granites and gneisses within which are smaller bodies of gabbro. Though evidence of the presence of the gabbro is obtained repeatedly along the belt by outcrops and surface fragments, it seems that the belt is not one elongated mass of gabbro, but consists of a number of smaller masses having a linear distribution along the belt. The ore bodies are segregations within these small gabbro masses and do not constitute a continuous body extending the entire length of the belt.

Surface outcrops of the ore bodies are lacking, and as the old workings have all caved in the character of the ore can be judged only from the surface fragments. A detailed examination of the belt was made by Lesley[a] for a Philadelphia mining company, and trenching was done at a number of points to expose the ore. Dr. Lesley consequently had unusual opportunities for observing the ore bodies, and his account of them is the most valuable we have. Shortly after this the belt was visited by Prof. W. C. Kerr and Dr. F. A. Genth, and described in a report of the North Carolina geological survey.[b] The descriptive part is taken mainly from Lesley's report, but 16 additional analyses made by Genth are given. This same report was reprinted with slight alterations in 1883[c] and again in 1893.[d] A brief sketch is also given in the Tenth Census reports.[e]

It is not surprising that Dr. Lesley at that early date misinterpreted the genesis of the ores. He regarded them as bedded deposits of sedimentary origin, and consequently the conclusions he drew as to the geology and structure of the deposits are erroneous. These are of historical interest only and will not be repeated here. The records of his observations, however, supply facts no longer accessible on account of the filling of the old workings and trenches. The ore bodies consist of strings of lens-shaped masses, continually enlarging and contracting in thickness from a few inches to 6 and 8 feet. "The principal beds may be safely estimated at an average of 4 feet, and in the best mining localities the average yield of a long gangway may reach 5 feet." The occurrence of the ore body in a series of disconnected lenses is consequently verified by the observation of Prof. Lesley.

TUSCARORA MINE.

This mine was worked in the seventies by a Philadelphia mining company. Forges were erected on a small stream a half mile northeast of the principal shaft, and considerable iron is said to have been made. It seems that the titaniferous ores could readily be smelted in the old Catalan forges and yielded a superior grade of iron. The Tuscarora mine consisted of several shafts extending about a mile along the ore belt. The principal shaft, the Sargeant, was situated a mile and a half north of Friendship. It reached a depth of 109 feet, and a tunnel run in from this depth is said to have cut a bed 12 feet wide.

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[a] Lesley, J. P., Note on the titaniferous iron-ore belt near Greensboro, N. C.: Proc. Am. Phil. Soc., vol. 12, 1871, pp. 139-156.

[b] Report of the Geological Survey of North Carolina, vol. 1, 1875, pp. 236-250.

[c] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geol. Survey of North Carolina, 1888, pp. 143-154.

[d] Nitze, H. B. C., A preliminary report on the iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 1893, pp. 60-68.

[e] Tenth Census, vol. 15, 1886, pp. 308-311.

Outcrops of granitic gneisses occur in the vicinity of the mine, but the immediate country rock is a gabbro. It is an olivine gabbro with diabasic texture, in which the feldspar laths reach a length of 2½ mm., and the pyroxene and olivine grains have a diameter of 1 to 1½ mm.

No ore in place is now exposed, but judging from fragments lying about on the surface it is a medium to coarse grained ore of good grade, in which the principal gangue consists of tufts and seams of chlorite and small quantities of material so decomposed as to make it undeterminable. Analyses 25 to 27 give the composition of the ore.

METALLOGRAPHIC DESCRIPTION OF ORE.

Polished sections of this ore show very striking features. Gangue minerals constitute only a small part of the surface. Ilmenite grains make up one-fifth to two-fifths of the surface; and they range in size from 2 mm. to 0.2 mm., though very few fall below 0.5 mm. in diameter. The most striking feature of the ore is the ilmenite intergrowths in the magnetite, which attain a coarseness not approached in any of the other ores that have been studied. Indeed, so coarse are they as to be easily discernible with the naked eye. An etched specimen of the ore is shown in Plate II, *C*, in which the relations of the ilmenite and the magnetite grains and the heavy ilmenite laths in the magnetite are apparent. The individual ilmenite plates have an average length of 2 mm., but some attain a length of as much as 4 mm. The space between the parallel plates varies from 0.2 to 0.5 mm., and the plates themselves may be as thick as 0.1 mm. Another characteristic feature is protuberances or local thickenings of the plates. This most frequently takes place at one end, the other end thinning out, giving an elongated, wedge-shaped appearance. These plates are plainly visible on cleavage faces of the magnetites on the unpolished surfaces of pieces that have been etched, and are frequently coarse enough to peel off with the edge of a knife blade. The structure is shown in Plate VII, *A*.

POSSIBILITIES OF UTILIZING ORE.

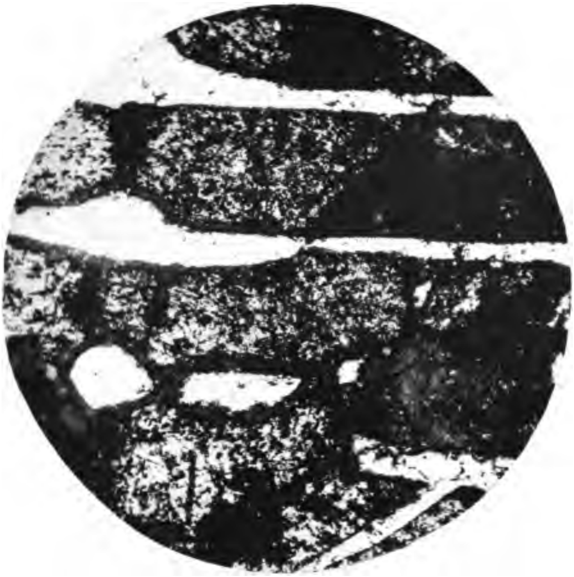
The most satisfactory results of magnetic separation were obtained from this ore, as shown below:

Results of magnetic separation of Tuscarora ore.

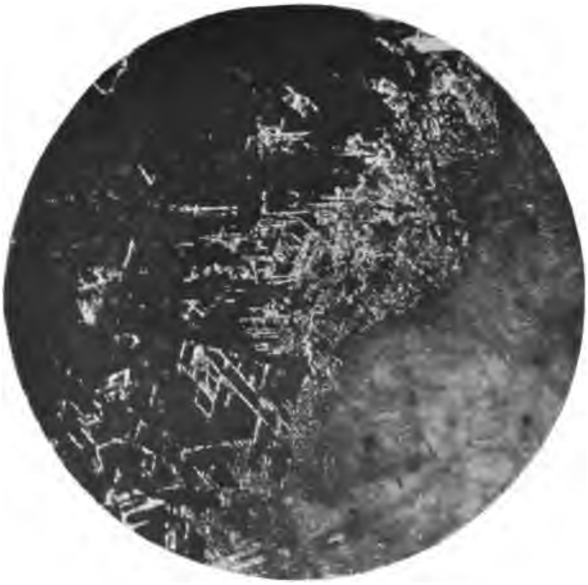
	Unscreened ore.	Ore through 50-mesh, over 100-mesh.[a]		Ore through screen finer than 100-mesh.[b]
		Magnetic.	Nonmagnetic.	Magnetic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity		71.5	28.5	70.1
Fe	58.07	67.76	33.76	68.41
TiO_2	12.82	4.25	34.32	3.64

[a] 44.6 per cent.

[b] 55.4 per cent.



A. TUSCARORA MINE, N. C., ORE. (× 60.)



B. IRON LAKE, MINN., ORE. (× 60.)

These results show that little is to be gained by grinding finer than 50-mesh; that is, notwithstanding the coarseness of the ilmenite intergrowths they are still too fine to be separated by grinding to 100-mesh. This of course is obvious from a comparison of the dimensions of the intergrowths given above and the size of the openings of the 100-mesh screen. If all the TiO_2 in the tailings is assigned to the ilmenite, they contain about 75 per cent ilmenite, with a residue of 6.38 per cent Fe. Some of this iron occurs in the gangue minerals present, so that very little magnetite is lost by adhering to the ilmenite or gangue. Although the titanium content of the concentrate is still higher than is acceptable in present blast-furnace practice, the concentrate is so high grade that it would make an acceptable ore to mix with titanium-free ore.

Kerr[a] gives the results of a magnetic-separation test made with a common magnet on ore obtained from this same belt several miles northeast of the Tuscarora mine. They are even more favorable than those presented above.

Results of magnetic-separation test of Tuscarora ore.

Constituent.	Natural ore.	Magnetic.	Nonmagnetic.
	Per cent.	*Per cent.*	*Per cent.*
Fe	41.95	67.60	21.63
TiO_2	15.35	1.27	16.20
SiO_2	12.75	1.30	26.80

TRUEBLOOD PLANTATION ORE.

About 2 miles northeast of the Tuscarora mine, on the south side of Brushy Creek, a little work has been done. The ore here also occurs in association with a gabbro. The gabbro is strongly uralitized and the feldspar sufficiently altered to make the twinning obscure in places. Diabasic texture is far less prominent than in the rock of the Tuscarora mine, and often lacking entirely. The average size of the grains is about 2 mm.

The ore is not quite as coarse as the Tuscarora mine ore, and etched sections do not show the intergrowths as abundantly. Otherwise the ore at the two localities is very similar in appearance.

APPLE PLANTATION ORE.

Some pits were put down on the Apple plantation just over the line in Rockingham County, southeast of the Haw River, but they are all filled now. Fragments of ore found on the surface are similar to the ore found on the Trueblood plantation. Of special interest to this locality are fragments of pink and gray emery. The occurrence of emery in this belt is first mentioned in Kerr's report,[a] in which he gives two analyses made by Genth. One analysis is of a reddish granular ore (analysis 52), which he describes as follows: "It has much the appearance of a granular reddish-brown garnet, for which it has been mistaken, until the analysis proved it to be not a silicate mixed with granular magnetite, but corundum." The other is of a granular grayish ore (analysis 53) described as follows: "This is of a similar quality and is found at the same locality; the minute grains of corundum have a yellowish or brownish-white color, and show in many places cleavage fractures, which give it the appearance of a felspathic mineral." No mention is made of the locality where these specimens were found. Pratt and Lewis[b] state that the exact location is not now known, and give the McCarviston or McCuiston place, 7 miles northeast of Friendship, in Guilford County, as the probable location. The specimens found on the old Apple plantation fit the description given by Kerr exactly, and as no such material was found anywhere else in the belt, it seems probable that this is the locality from which Kerr's specimens were obtained. The rock was not found in place and no conclusions could be drawn as to the occurrence and size of the deposit.

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[a] Report of the Geological Survey of North Carolina, vol. 1, 1875, p. 245.

DANNEMORA MINE.

Some work was done on the Shaw belt, 3 miles west of Summerfield, but the only extensive workings were those on the north side of the Haw River, close to the line between Guilford and Rockingham Counties. Ore was worked from pits in Revolutionary times, and hauled to Troublesome Forge, 5 miles to the north. Subsequently a Philadelphia mining company worked the Dannemora mine on this property. The following description of the mine, given by Bailey Willis in the Tenth Census report,[c] is quoted because it gives the size of one of the ore lenses:

> The first work was done in incline No. 1. According to the statement of the superintendent the ore gave out 10 feet from the surface but was found again 20 feet farther down; it widened to 12 feet, which is the thickness 90 feet from the surface in the incline, 70 feet vertically. At this depth a drift has been driven along the vein and stoping has been begun. A small winze has been sunk 20 feet farther on the incline, and the ore is said to narrow to 1 foot in thickness. Before the horizontal drift reached the second incline the ore was pinched out by the granite walls.
>
> As the ore body thus opened gives out just beyond incline No. 1, its dimensions are pretty well ascertained. It is approximately 125 feet long, 80 feet in incline width, and 12 feet thick. The drift has been extended to another lens of the same thickness, northeast of it, and the surface outcrops and trenches indicate the existence of others to the southwest. The ore is accompanied by chlorite and mica, which are sufficiently

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[a] Report of the Geological Survey of North Carolina, vol. 1, 1875, p. 246.

[b] Pratt, J. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, 1905, pp. 263-264.

[c] Tenth Census, vol. 15, 1886, p. 308.

decomposed, even at the depth of the tunnel, to be readily dug with a pick. The ore is separated on the surface, by screening, into lump and fine ore, the former being shipped for fettling, the latter for blast-furnace use.

The ore lying about the old workings is somewhat leaner than the Tuscarora-mine ore. It consists of a similar granular aggregate of ilmenite and magnetite with the gangue minerals, but the individual grains seldom exceed 1 mm. in diameter, and most of them are about 0.5 mm. Intergrowths of ilmenite in the magnetite grains are almost lacking.

SUMMARY.

The titanium content of these ores is about the normal one for titaniferous magnetites. Of the large number of available analyses the average TiO_2 content is about 13 per cent. The ilmenite and the magnetite occur as granular aggregates in the ores in such a manner that most of the titanium can be eliminated with little loss of magnetite. The resulting concentrate runs high in iron and is low enough in titanium to make possible the utilization of these ores in normal blast-furnace practice by mixing them with titanium-free ores. On the other hand, little is known in regard to their geologic occurrence and size on account of lack of exposures. Such conclusions as can be drawn from old data and the nature of the deposits are not very favorable to them. The ore bodies seem to be rather small and irregular in distribution, so that mining operations would be attended by considerable uncertainty. On the whole, therefore, the belt is not very promising as a source of iron ore.

LINCOLN COUNTY.

See Catawba County.

MACON COUNTY.

There are a number of occurrences of titaniferous magnetite in Macon County east and south of Franklin, but none has been explored more than superficially.

Five miles east of Franklin and one-eighth of a mile north of Culasagee Creek there is a heavy surface float of massive lustrous magnetite high in titanium (analysis 40). The gangue is quartz and chlorite; the ore is traceable for several hundred yards along the summit of a hill in a northeasterly direction parallel to the strike of the decomposed mica schists near the foot of the hill.

An analysis has also been made of the ore on land 4 miles southwest of Franklin and 2 miles above the mouth of Cartoogajay Creek (analysis 41). The ore is very fine grained, in a chloritic gangue, and in places slightly garnetiferous. The extent of the ore body is not apparent.

MADISON COUNTY.

No important bodies of titaniferous ore are known in Madison County, though there are several occurrences of the ore.

In the eastern part of the county, a half mile above the mouth of Paint Fork, small pieces of float ore high in titanium are found (analysis 43). The occurrence of a highly titaniferous ore is also noted near the road midway between Asheville and Burnsville (analysis 42).

An occurrence showing only a moderate amount of titanium is that a half mile east of the Haywood County line near the headwaters of Spring Creek (analysis 44). It has a thickness of 5 to 6 feet near the surface and appears to widen in depth.

MITCHELL COUNTY.

Titaniferous ores occur in Mitchell County in the Roan Mountain belt, the Pumpkin Patch Mountain belt, and on Iron Mountain.

Titaniferous ore occurs on one of the spurs of Iron Mountain 2½ miles above the mouth of Greasy Creek, near the Jenkins ore bank (analysis 49). The ore body consists of a compact lustrous ore free from gangue, and attains a width of 5½ feet. The wall rock is hornblende gneiss and pegmatite.

The Roan Mountain titaniferous belt lies several miles south of the Cranberry belt to which it is parallel. Its eastern extremity is near the mouth of Roaring Creek on one of the southern spurs of Big Yellow Mountain. It crosses the State line on the summit of Grassy Bald Ridge, then, after traversing the eastern edge of Tennessee for about 4 miles, bends around to the southwest and reenters North Carolina near the headwaters of Big Rock Creek; thence it continues to the mouth of Big Rock Creek to the Yancey County line at Toe River. No ore bodies of any size have been found along this belt. At the eastern end some prospecting has been done, including the drilling of three diamond-drill holes. The results were discouraging, as the ores occur in lenses of 2 inches to 2 feet in width. The titanium content is only moderate in amount (analyses 45 and 46). The ore is compact, lustrous, and free from gangue, and occurs in a country rock of very coarse-grained pegmatite, hornblende schist, epidote, and garnet rock.

At the southwest end of the belt on the north side of Little Rock Creek a small pit exposes a bed 3 feet wide, which at a depth of 4 feet is cut out by a diabase dike (analysis 48).

The Pumpkin Patch Mountain titaniferous magnetite belt lies to the northwest of Bakersville and has an extent of 5 to 6 miles. Some pits have been put down on the Parker place near the head of Wadkins Branch, 5 miles northwest of Bakersville, and loose blocks of ore encountered (analysis 47); the pits did not go deep enough to get the ore in place.

All of these Mitchell County ores show approximately the same titanium content.

ROCKINGHAM COUNTY.

See Guilford County.

YANCEY COUNTY.

The occurrences of iron ore in Yancey County are isolated and sporadic, and no notable occurrences of titaniferous ore have been disclosed.

In the extreme western part of the county near the head of Possum Trot Creek, 9 miles west of Burnsville, is found float ore that shows a small amount of titanium (analysis 57). It is possible that this occurrence belongs to the Roan Mountain titaniferous belt of Mitchell County.

Another deposit occurs 6 miles north of Burnsville, on the south side of Mine Fork, a half mile above its mouth (see analysis 56). Two small openings were made 75 feet apart on the strike of the ore (N. 25° E.) and show a vertical bed of ore 6 to 10 feet across. The ore is in a gangue of chlorite, small particles of quartz and feldspar, and a peculiar brown mineral of high luster which may be rutile or brookite. A quarter mile southwest of these openings is much surface float of this heavy brown mineral nearly free from magnetite. If this mineral is really rutile or brookite, considerable titanium could easily be eliminated by magnetic concentration.

MINNESOTA.

Titaniferous magnetite occurs within an extensive area of gabbro in northeastern Minnesota known as the Duluth laccolith. This forms part of the pre-Cambrian region of Lake Superior, and the geology and petrography of it have been referred to repeatedly by the geologists who have worked in this field. The geology of the ore bodies is so simple and that of the entire area so complicated that it would be a needless use of space in this report to attempt to give a résumé of the geological literature embracing this area. A bibliography of the literature is given in Monograph 52 of the United States Geological Survey.[a]

Describing the areal distribution of the great gabbro mass Elftman[b] says:

> The gabbro forms the outer or northern member of the Keeweenawan series. The general shape of the area is crescentic with the concave side toward Lake Superior.

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[a] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey, 1911, pp. 78-80.

[b] Elftman, A. H., The geology of the Keeweenawan area in northeastern Minnesota: Am. Geol., vol. 22, 1898, p. 132.

The horns of the crescent are located, the one near Duluth and the other near East Greenwood Lake, T. 64 N., R. 2 E. The chord connecting them is 125 miles long and runs northeast and southwest. The maximum width of the area is 25 miles. The surface area is about 2,400 square miles in extent.

PETROGRAPHY OF THE GABBRO.

Detailed petrographic descriptions of the gabbro are given in several of the articles cited in the bibliography mentioned above. For the purposes of this description the concise statement made by Van Hise and Leith [a] will suffice.

> It is, for the most part, normal gabbro, but it has many facies. Mineralogically it varies from a very magnetitic gabbro through olivine gabbro in which the feldspar is subordinate and ordinary olivine gabbro to olivine-free gabbro, or ordinary gabbro, and finally to a rock in which feldspar is the dominant mineral, the rock being a labradorite or an anorthosite. * * *
>
> Structurally the gabbro is ordinarily massive. However, at many places, especially near its borders, it has a sheeted structure. Some of the sheets are very thin and strongly resemble bedded rocks. * * * In addition to this sheeted structure there is a banded structure, due to the parallel arrangement of the mineral constituents.
>
> Texturally the gabbro varies from a rock of very coarse grain to one that is almost aphanitic. All varieties, coarse and fine, are granulitic.

AGE AND RELATIONS OF GABBRO TO OTHER FORMATIONS.

The age and relation of the gabbro to the formations with which it comes in contact have been variously interpreted by different workers. The interpretation of Van Hise and Leith is most in accord with the facts now available and is the one here given.[b]

> The structural relations of the Duluth gabbro are very interesting. On the north, in passing from St. Louis River to Grand Portage, the gabbro is in contact for a long way with the upper Huronian, then for many miles with the several members of the lower Huronian and the Archean, and finally for many miles again with the upper Huronian. It thus cuts diagonally across the upper Huronian in its northern and southern parts and in passing toward the center of the area goes through the lower Huronian and deep into the Archean.
>
> Evidence of its intrusive character is afforded by its coarse crystallization; by the presence of numerous subordinate bosses and dikes, offshoots of the gabbro mass, in the Huronian series; by the inclusion of isolated masses of upper Huronian near its margin and the profound metamorphic effects of the gabbro, the rocks being changed to schists or gneisses or even completely granular crystalline rocks for distances up to half a mile or a mile from the main gabbro mass, an effect not to be expected from a rapidly cooling extrusive; and finally by the higher density of the gabbro than of the intruded rocks.
>
> The relations of the gabbros to the lavas of the coast have not been satisfactorily determined. Their contact is mainly in the plateau of the interior, is very poorly exposed, and has not been sufficiently studied. However, it is believed that when these relations are worked out it will be found that the gabbro is intrusive and has produced profound metamorphic effects.

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[a] Op. cit., p. 372.

[b] Op. cit., pp. 372–373.

If this inferred intrusive relation is confirmed, the Duluth gabbro is a great laccolith, which has as a basement the Huronian and Archean, and as a roof the Keeweenawan lava flows. The relations of the Duluth gabbro to the Puckwunge conglomerate at the base of the Keeweenawan and to the earlier Keeweenawan lavas have not been established. Until this is done it is impossible to gain any conception as to how far Keeweenawan time had advanced before the appearance of the gabbro. If the Duluth gabbro is interpreted as a laccolith it surpasses in magnitude any other yet described. With a maximum diameter of 100 miles, if its thickness has approximately the ratio shown in the typical laccoliths of the Henry Mountains,[a] the thickness would be 75,000 feet. If an average dip of 10° for 50 miles on the north shore is assumed the thickness would figure 45,000 feet.

The intrusion of so vast a mass of material must have required a long time. The parts earlier intruded were doubtless solidified long before magma ceased to enter. Thus offshoots of these later parts would be found as dikes in the earlier solidified parts. There would be great variation in its coarseness of crystallization. Ample time would be afforded for differentiation by fractional crystallization, separation by gravity, and other processes, and thus is explained the structural complexity of the gabbro and its great variation in mineral and chemical character.

TITANIFEROUS MAGNETITES IN THE DULUTH GABBRO.

The occurrence of titaniferous magnetite in the gabbro of northeastern Minnesota has been known for nearly 40 years, and numerous references to the deposits are found in the literature. The data supplied, however, are of such an indefinite and general character that little conception can be gained of the actual economic importance of the ores. The quotations and abstracts in the following paragraphs include practically all the information that has been published in regard to them. The list is, by no means, however, a complete record of references to the deposits.

In the report of the State chemist, S. F. Peckham, for the year 1876, is the following statement:[b]

> A sample of iron ore, supposed to contain tin, from the neighborhood of Duluth, was sent to Prof. E. W. Morley, of Hudson, Ohio, a gentleman of large experience on iron assays. He reported two assays as yielding iron, 16.19 per cent and 16.17 per cent. "Tin not present in any appreciable quantity. The ore appeared to contain quite a notable quantity of titanium. * * *." Another sample of iron ore from near Duluth sent to Prof. Morley was reported as "an iron-magnesium-sodium silicate; with not enough iron to make it of value as an iron ore."

Referring to this statement in 1887, Winchell says:[c]

> At that time some local interest was awakened over the supposed existence of valuable ore deposits within the corporate limits of the city of Duluth. It is sufficient to say that the excitement soon subsided when it became known that the ore was likely to run low in iron, and that the amount that was known to exist was quite limited. Besides these facts, the presence of a considerable percentage of titanium would have operated disastrously upon the enterprise had the discovery been pushed far enough to have been worthy of the name.

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[a] See Gilbert, G. K., The geology of the Henry Mountains: U. S. Geog. and Geol. Survey, Rocky Mtn. Region, 1880, p. 55.

[b] Fifth Annual Report of the Geological and Natural History Survey of Minnesota, 1876, p. 63.

[c] Winchell, N. H., Fifteenth Annual Report of the Geological and Natural History Survey of Minnesota, 1886, p. 212.

Winchell,[a] referring to ore which he found on the north shore of Iron Lake, says: "This iron ore constitutes what is locally known as the 'Mayhew Iron Range,' and is found in a belt about a mile wide on both sides of Iron Lake, and on the south side of Portage Lake, and between Portage and Poplar Lakes. An analysis reported by Mr. Hause, performed by R. S. Robertson, of Pittsburgh, Pa., gave the following result: Silica, 2.02; alumina, 2.68; titanium, 12.09; sesqui chromium, 2.40; mag. ox. iron, 80.78; lime, trace; phos. acid, 0.03." A careful study of this location warranted among others the following statements:[b]

> First. The ore is in the igneous rock.
>
> Second. It varies in quality very much, even passing into rock that can not be styled iron ore.
>
> Tenth. The iron in considerable but unknown quantity is of fine quality, being seen in other places besides this described.
>
> From several assays Mr. Hoare states that he ascertained the iron and titanium together in the ore from Iron Lake to be pretty nearly uniform throughout, but that the titanium varied from 6 to 13 per cent, displacing about the same percentage of iron. The ore is in enormous quantities, in one place laid bare so that he crossed over it 30 paces.

A year later, in a report on the mineralogy of Minnesota, Winchell[c] said of menaccanite:

> This seems to be the principal magnetic mineral which enters into the gabbro and other igneous rocks of the Cupriferous in Minnesota. It is so abundant in the region of Iron Lake, north of Grand Marais, and at Herman, near Duluth, that it has attracted attention as an iron ore. The titanium present is frequently not enough to constitute the mineral, which requires from 30 to 40 per cent. It is sometimes as low as 3 per cent, the mineral then being rather titaniferous magnetite.

Irving[d] mentions the same localities. In speaking of the orthoclase-bearing gabbros, he says:

> In some of these rocks the titaniferous magnetite forms bunches of such size as to have attracted attention as an iron ore, as, for instance, at Duluth, and again at several points in the interior back of Grand Marais and Beaver Bay. From some of this ore obtained some miles back of Grand Marais I obtained, some years since, over 10 per cent of titanic acid.

In 1887, Winchell[e] mentioned the occurrence of titaniferous iron ore in abundance on the shore of Gabimichigama Lake. In a letter to the author dated January 28, 1912, Mr. John G. Howard, of Duluth, writes the following in regard to this same locality: "The ore marked from section 7–64–5 and section 12–64–6 comes from the county line between Cook and Lake, and crosses the line and outcrops in

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[a] Winchell, N. H., Tenth Annual Report of the Geological and Natural History Survey of Minnesota, 1881, p. 81.

[b] Idem, pp. 80–81, 85.

[c] Winchell, N. H., Eleventh Annual Report of the Geological and Natural History Survey of Minnesota, 1882, p. 17.

[d] Irving, R. D., The copper-bearing rocks of Lake Superior: Mon. 5, U. S. Geol. Survey, 1883, pp. 51-52.

[e] Winchell, Alexander, Fifteenth Annual Report of the Geological and Natural History Survey of Minnesota, 1886, p. 167.

Lake County in section 12–64–6, and also in section 7–64–5, Cook County. This is a fine large outcrop and assays as follows: Iron, 56.16; phosphorus, 0.003; silica, 2.40; manganese, 0.40; lime, 0.04; magnesia, 1.35; sulphur, trace; titanium, from none to 6. This deposit shows on surface for over a mile in length and shows lots of clean ore." Mr. Howard also states that there are a number of deposits between this location and Iron Lake, which lies about 18 miles to the east. Another analysis furnished by Mr. Howard comes from a locality still farther west in section 30–63–9, and is as follows: Iron, 55.04; phosphorus, 0.003; silica, 6.20; lime, 0.15; manganese, 0.28; magnesia, 2.28; alumina, 8.85; sulphur, 0.876; titanium, from 2.50 to 19.

Wadsworth,[a] in describing the Duluth gabbro, says: "Others, again, have the magnetite abundantly developed, so much so that the grayish-black rock has been designated an iron ore, which has been mined at Duluth." Again he says:[b] "In local modifications of gabbro, the magnetite predominates to such an extent over the other minerals that it is mined as an iron ore. The quantity of this ore is very great, and a number of mines exist upon it at various localities, * * * the only apparent limit to it being extensively mined is owing to the titaniferous nature of the ore. * * * These ores generally seem to be titaniferous magnetite, the titanium varying from a minute amount up to 12 per cent or higher."

Winchell again refers to Iron Lake in the sixteenth annual report of the geological and natural history survey of Minnesota. He says:[c]

> The rim of the lake is mostly massive gabbro. This in places is so strongly charged with magnetite that one might truthfully conceive of the prison lake as iron-bound. The abundance of the magnetite caused attention within a few years to be directed to the region, but investigation showed the ore to be strongly titaniferous.

Describing a point on the north shore, he says:[d]

> Black sheets of magnetite are seen spreading out in the gabbro in an irregular way. Here and there fragments of the gabbro are involved in it. The appearance is as if the magnetite had existed previously and been introduced into the mass of fluid gabbro and never generally diffused.

Winchell,[e] describing the different kinds of iron ore found in northeastern Minnesota, says:

> The third variety of iron ore is also magnetite. It is coarse and has a duller luster than the Animikie ore and is not so strongly magnetic. It is found in many places in the gabbro, which sometimes contains so much of it that it seems to be pure mag-

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[a] Wadsworth, M. E., Preliminary description of the peridotytes, gabbros, diabases, and andesytes of Minnesota: Bull. 2, Geol. and Nat. Hist. Survey of Minn., 1887, p. 49.

[b] Idem, pp. 63, 64.

[c] P. 304.

[d] P. 305.

[e] Winchell, H. V., Seventeenth Annual Report of the Geological and Natural History Survey of Minnesota, 1888, pp. 80–81.

netite. This ore almost always contains a large amount of titanic acid which ruins it for merchantable ore, with only present methods of reduction. Immense deposits of this titaniferous ore are found, and most of them have been purchased from the United States Government in the hope of being able to conduct remunerative mining operations. When a method for reducing titaniferous ores cheaply is discovered, such iron ore will be valuable; but until then it is worthless.

An analysis of a sample of this ore from section 36-63-10, as reported by Mr. C. F. Sidener, is:

	Per cent.
Silica, SiO_2	11.37
Alumina, Al_2O_3	1.32
Magnetic oxide of iron, Fe_3O_4	53.33
Protoxide of iron, FeO	14.42
Oxide of titanium, TiO_2	16.03
Lime, CaO	.10
Magnesia, MgO	2.73
Phosphorus, P	.01
Sulphur, S	Traces.
	99.31
Metallic iron, Fe	49.40

In this same report he says:[a]

> Speaking of the gabbro on Mayhew Lake, this gabbro contains considerable magnetite. Several claim cabins are located on this gabbro ore. The gabbro in Tucker Lake just west of Mayhew Lake is also magnetitic. * * * In the SE. ¼ NW. ¼ sec. 2, 64-3 the gabbro contains parallel bands of magnetite which dip S. 40° and give the rock a decidedly stratified aspect. Some of the beds or bands of magnetite are 4 or 5 inches thick, others only a fraction of an inch.

U. S. Grant, in the report mentioned,[b] refers to another locality on Mayhew Lake. He says:

> On the end of the little point which is in the SE. ¼ SE. ¼ sec. 36, the gabbro has changed somewhat, and on the south side of this point it surrounds a large mass of iron ore. This ore seems to be principally magnetite, with a little scattering feldspar, but as it is in the gabbro, it very probably contains a considerable amount of titanium. The exposure of ore was 30 feet wide, and extended for about 300 feet along the shore, rising 15 feet above the water. The contact between the ore and gabbro was found at one place; here the gabbro does not pass into the iron ore by gradually acquiring more magnetite, but there is a sharp and distinct line between the two.

In Bulletin 6 of the Minnesota survey, on the iron ores of Minnesota, four groups of iron ores are recognized, one of which is called the "gabbro titanic-iron group." This is described as follows:[c]

> There is certainly no iron ore in Minnesota which is known to exist in larger amounts than this. The explorer in the iron region is continually finding this ore in immense masses, and it has been the cause of many visits by intending purchasers. Fortunately the lithologic characters that surround it are so simple, uniform, and evident that the tyro may discern them. The belt that carries this ore is wide, and it extends

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[a] Op. cit., p. 105.

[b] Op. cit., p. 169.

[c] Winchell, N. H., and Winchell, H. V., The iron ores of Minnesota: Bull. 6, Geol. and Nat. Hist. Survey of Minn., 1891, p. 123.

> from Duluth to Pigeon Point, constituting, in its culminating topographic points, the summits of the Mesabi Range.

The bulletin[a] states further:

> The gabbro titanic-iron group of lithologic characters has been described. It is only necessary to say here that the ore is a black, massive magnetite, generally of coarse, hackly crystalline fracture, and when pure and in large quantities, as it is frequently, it appears in bold and bald knobs, and is dispersed irregularly through the gabbro of the Mesabi Range.
>
> It seems to be only a highly magnetited condition of the structureless gabbro rock itself. This ore was first seen by the officers of the survey at Mayhew Lake, north from Grand Marais. Mayhew Lake is sometimes known as Iron Lake.
>
> This iron is in considerable but unknown quantity at this place, but appears in a similar manner in many places in the vicinity of Mayhew Lake, toward the southwest and west, as well as toward the southeast. This ore may also be seen in the gabbro within the corporate limits of Duluth, where it appears simply as a very highly ferruginous condition of the gabbro, with the other gabbro minerals as its impurities. There is no place within the area of the gabbro sheet where this ore may not exist, as its appearance is entirely fortuitous, but its quality varies from nearly pure magnetite (or menaccanite) to simply magnetitic gabbro.

This report[b] also gives three analyses in addition to those already cited, as follows:

Results of analysis of ore from section 36, 65–3 W. (Iron Lake).

[Analyst, Prof. J. A. Dodge.]

Silica	20.90
Alumina	1.75
Lime	Trace.
Magnesia	2.63
Titanium binoxide	2.23
Phosphorus	None.
Protoxide of iron	2.01
Magnetic oxide of iron	70.29
	99.81
Metallic iron	52.46

Results of analysis of iron sand from Black Beach, near Beaver Bay.[c]

[Analysts, J. A. Dodge and C. F. Sidener.]

Silica	65.17
Magnetic oxide of iron	30.06
Protoxide of iron	2.23
Dioxide of titanium	2.48
Lime	Trace.
Magnesia	Trace.
Alumina	Trace.
	99.94
Metallic iron	23.50

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[a] Op. cit., pp. 135–136.

[b] Op. cit., pp. 141–142.

[c] The statement is made that the sand is derived chiefly from the decomposition of titaniferous gabbro. Bayley states, however, that the rock of Beaver Bay is not a part of the Duluth gabbro, but probably a part of a sheet or sill intrusive in the Keeweenawan, and occurring at a much higher horizon (Jour. of Geol., vol. 2, 1894, p. 819).

Results of analysis of iron sand from the SW. ¼ sec. 33, 61-12, south shore of Birch Lake.

[Analyst, Prof. J. A. Dodge.]

Silica	5.19
Alumina	2.95
Lime	Trace.
Magnesia	.35
Phosphorus	None.
Titanium dioxide	36.77
Metallic iron	41.12

Bayley, in discussing the peripheral phases of the great gabbro mass of northeastern Minnesota, speaks of the titaniferous magnetites. He says:[a]

> The specimens in the possession of the United States Geological Survey all contain a large proportion of magnetite, which in some cases runs so high as to constitute 90 per cent of the entire rock. These latter rocks have the bright metallic luster of magnetite and usually a finely granular texture. The luster frequently becomes very brilliant and the specimen takes on the peculiar pinkish tinge of ilmenite. A careful inspection of such specimens as seem to be pure ore reveals the presence in them of tiny yellowish-green grains of olivine, but these are so rare that they produce but little impression on the general aspect of the rock. When the magnetite makes up practically its entire body the rock is much jointed, and, consequently, it easily breaks into small irregular or cuboidal fragments, as Winchell has already noted, and these are not unfrequently natural magnets. Tests of magnetites of this kind from the shores of Little Sasaganaga Lake, NW. ¼ sec. 7, T. 64 N., R. 5 W., prove them to be very rich in titanium, as was surmised from their pinkish tinge.

The ore and its occurrence were described by Elftman in 1898. In a discussion of the minerals of the gabbro, he says:[b]

> Magnetite is scattered throughout the rock. Ordinarily it occurs in small grains usually having perfect crystal outlines. Large irregular areas, making up a large part of the rock, are found in some sections. The proportion increases until the entire rock is made up of this mineral. Chemical examinations show that the mineral is sometimes free from titanium, but usually the latter constituent is present in varying amounts up to 20 per cent.

Elftman gives the following description[c] of the occurrence of the ores:

> Small masses of titaniferous magnetite are scattered throughout the gabbro. Extensive masses are known only along the northern border and in the eastern part of the gabbro. These deposits of magnetite are especially numerous in the region between Brule Lake and the northern limit of the gabbro. The ore bodies are found in three belts running east and west. The northernmost follows the boundary of the gabbro. The second runs through the southern part of township 64 north, and the southern or third belt runs south of Brule Lake through the central or southern part of township 63 north.
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> The magnetite deposits are usually associated with granulitic norite, which is always the slightly older of the two. The norite is considerably broken and traversed by

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[a] Bayley, W. S., The basic massive rocks of the Lake Superior region: Jour. of Geol., vol. 2, 1894, p. 818.

[b] Elftman, A. H., The geology of the Keweenawan area in northeastern Minnesota: Am. Geol., vol. 22, 1898, p. 140.

[c] Op. cit., pp. 145-146.

veins of magnetite extending from the larger masses around its edge. From the main mass of the magnetite stringers and apophyses run several hundred feet into the massive gabbro. Frequently the magnetite occurs in numerous parallel bands several inches to a foot in width, which alternate with bands of the associated gabbro. As many as 25 of these bands have been noticed within a belt 10 feet wide. There are all proportions of minerals between magnetite and the normal phase of the gabbro. The variations of the ore as seen in a shaft 19 feet deep on section 21, T. 63 N., R. 4 W., are as follows: At the surface the rock was composed of solid coarse magnetite stained green with a coating of malachite. The pure magnetite continued downward for 5 feet, when a few grains of chalcopyrite, pyrite, and plagioclase were found. At 7 feet below the surface the magnetite became fine grained, and a small amount of plagioclase and pyrite continued. Olivine appears as bright, yellow grains. Continuing downward the plagioclase and pyrite disappeared and the lower 10 feet of the shaft were in magnetite, with the olivine increasing in proportion.

The ore has a shining black luster, is brittle, and usually coarse grained. Thin sections of the apparently pure ore generally show the presence of small particles of plagioclase, and sometimes of other minerals. * * *

Chemical analyses show quite a variation in the composition of these ores. An analysis by[1] the writer of an ore from sec. 21, T. 63 N., R. 4 W., gave silica, 6.08; alumina, 3.82; lime, 1.69; titanium oxide, 14.73; magnetite, 71; nickel oxide, 2.65; sulphur, trace. The lime and alumina are accounted for by the presence of a triclinic feldspar.

Titanium is sometimes absent. Cobalt, manganese, and chromium are sometimes found in addition to the constituents given in the above analysis. The metallic iron varies from 49 to 60 per cent. These extensive magnetite deposits at present afford the only ores from the gabbro of probable economic value.

After describing the character of the titaniferous ore deposits in the gabbro, Clements[a] says of them:

> The injurious effect of the titanium in rendering the magnetite unmarketable would of course apply to these titaniferous magnetite bodies whatever their size. However, so far as we know, up to the present time no published description has been given of any large continuous masses of the practically pure titaniferous magnetite.

The following recent statement concerning these ores by Van Hise and Leith[b] is in the nature of a summary of existing knowledge, and for that reason is quoted in full:

> The great gabbro mass of Lake and Cook Counties, Minn., contains much magnetite, both disseminated and segregated into ore deposits. Complete gradation may be observed between gabbro carrying little magnetite and magnetite carrying little of the ferromagnesian constituents and feldspar. The known deposits are extremely irregular, with gradations between themselves and the gabbro and containing within themselves much gabbro material. They weather very much like the gabbro and might be easily unnoticed on the weathered surface. There has been little exploration for these ores. A few drill holes have been sunk in the region south of Gunflint Lake, some of them revealing depths of ore aggregating several hundred feet. The known deposits seem to be distributed in irregular zones roughly parallel to the north or basal margin of the Duluth gabbro.

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[a] Clements, J. M., The Vermillion iron-bearing district of Minnesota: Mon. 45, U. S. Geol. Survey, 1903, p. 421.

[b] Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: Mon. 52, U. S. Geol. Survey, 1911, p. 561.

The composition of the ore averaged from 3,560 feet in 14 drill holes is 48.8 per cent iron. The range is from 54 to 20 per cent. The high titanium content renders the ores of doubtful value for the present.

Where the gabbro comes into contact with the iron-bearing Gunflint formation both formations carry magnetite so similar in texture that it is difficult to tell one from the other. However, on analysis the gabbro magnetite is found to be titaniferous, whereas that of the Gunflint formation is not titaniferous. This fact seems to argue against any considerable transfer of material from the gabbro to the iron-bearing formation during its alteration.

The titaniferous magnetites of northeastern Minnesota are direct magmatic segregations in the Duluth gabbro, according to all of the geologists, who have studied them, including Irving, Merriam, Bayley, Grant, Winchell, Clements, Van Hise, Leith, and others. The complete gradation from gabbro with a small amount of original magnetite to a magnetite with small amounts of amphibole and other gabbro minerals can be seen in almost any part of the titaniferous magnetite deposits. It is scarcely necessary to repeat the detailed petrologic evidence so fully given by the writers named.

Evidence is given elsewhere for the intrusive character of the Duluth gabbro. It cooled far beneath the surface, where there was not easy escape for its solutions. This fact is taken to explain its retention of its iron oxide. It has been argued under an earlier heading that where basic rocks of similar composition reached the surface large quantities of iron escaped and became available for ordinary sedimentary deposition.

The area underlain by the Duluth gabbro is for the most part an uninhabited region of woods and lakes, where the only means of travel is by canoe. It was impossible and also useless for the purposes of this report to have visited the whole of such a vast area. It was also apparent from the literature that the actual importance of these deposits with respect to size and iron content was open to doubt. It was decided, therefore, to visit the most promising region within the gabbro area. Judging from the published descriptions this seemed to be the area about Iron Lake. Responses to inquiries made of numerous geologists, prospectors, and others who were familiar with the area also pointed to the Iron Lake region as having the most promising showing of ore. It was further learned that considerable drilling had been done there some years ago, and the drill records and detailed maps were very kindly placed at the writer's disposal. Consequently the region about Iron Lake was selected as the one to be visited, and the following paragraphs are an account of the observations made there.

IRON LAKE REGION.

A week was spent in this region with Nicholas Probek, of North Lake, as guide. The familiarity of Mr. Probek with the country made possible the careful examination of a large area. The area examined was the country adjacent to Tucker, Iron, Portage, and Poplar Lakes. It is a narrow belt extending on both sides of the town line between T. 64 N. and 65 N., and from the middle of R. 1

W. to the middle of R. 3 W. For convenience of discussion the region is considered under subheadings corresponding to the lakes above mentioned.

TUCKER LAKE.

Tucker Lake is a narrow lake with its axis lying nearly east-west. It extends from near the western edge of section 4 to near the middle of sec. 1, T. 64 N., R. 3 W. Its eastern end is divided into a northern and southern arm by a narrow peninsula. Its outlet is at about the middle of the north shore.

Along the north and south shores of the lake in the neighborhood of the outlet, and for some distance along the outlet, are almost continuous rock exposures. The prevailing rock is the normal gabbro, in many places with considerable feldspar, so that it has a light color. Magnetite occurs throughout the rock in sparsely disseminated grains. The most prominent femic constituent is the pyroxene, which has usually to a great extent undergone uralitization. Biotite is locally abundant in intimate association with the pyroxene, and seems to be a secondary product. At several places the normal coarse gabbro gives way to a fine-grained rock of brownish-gray color. Thin tablets of feldspar, 1 cm. long and less than 1 mm. thick in parallel arrangement, give this rock at times a schistose appearance. Certain phases of this rock are rather heavy and weather with a black surface suggesting magnetite. A careful examination of this rock, which has been called ore, shows that it contains only a small amount of ore minerals. At only one point, on the south shore, a little west of the outlet, is there anything that could be called ore. The gabbro here contains a small segregation of ore 25 feet long. The greater part of this is very lean, being nothing more than gabbro in which the feldspar has become subordinate and the pyroxene the most prominent constituent. Magnetite is present in considerable amount, and makes up a rock which at first sight appears to be good ore. A closer examination reveals a large quantity of black augite and considerable olivine. A polished section of one of the richest pieces of this ore showed that less than half consists of ore minerals, and this is almost entirely ilmenite.

A half mile north of the outlet at Tucker Lake, in the SE. ¼ sec. 34, T. 65 N., R. 3 W., is an opening in an ore body. The pit has a length of 125 feet along the outcrop, which is here in the form of a ledge. Several hundred tons of ore have been blasted loose and the exposures are very good. The outcrop of ore can be traced about 100 feet east of the pit, beyond which it is covered with drift. To the west of the pit it is entirely covered. This ore body ranges in width from 8 to 10 feet, and passes into gabbro on each side. The ore itself is rather lean, and grades rapidly into normal gabbro, so that a sharp distinction can usually be made between gabbro and ore. Within the ore body are small inclusions of gabbro with boundaries so distinct against the surrounding ore as to have the appearance of real included fragments of the gabbro country rock and not segregations of the gabbroitic material in the ore. The relations of the contact and these inclusions would suggest that the segregation did not take place where the ore body is now found, but that the ore body was squeezed into its present position, perhaps while the gabbro was still in a molten or viscous state. Between this pit and the shore of Tucker Lake are several exposures showing schlierenlike ore bodies of still smaller size whose relations to the country rock suggest a similar origin. Northwest of the pit is a ledge of gabbro with a small band of lean ore running through it. In the leaner parts of the ore the pyroxenes are the most prominent gangue minerals; in the rich part, consisting almost entirely of the ore minerals, olivine is the most abundant gangue. Analyses of ore from this property are said to have shown about 18 per cent Ti.

Along the north shore of the north arm of Tucker Lake are a number of exposures of gabbro showing considerable iron. The ore occurs in small ferromagnesian-rich areas of the gabbro. These areas are characterized by the feldspar becoming subordinate in amount accompanied by a rapid increase in the amount of pyroxene. At the same time olivine and magnetite become prominent. This rock grades over into ore by magnetite, and, to a less extent, olivine, becoming more abundant at the expense of the pyroxene. The decrease in the amount of pyroxene is, however, more apparent than real as the dark pyroxene is difficult to recognize in the magnetite, whereas the clear yellow olivine stands out strongly against the black magnetite. At one point the ore swarms with fine needles of apatite. Here again polished surfaces show that the ore is not nearly so rich as would appear from hand specimens, and even the richest pieces do not show much more than 50 per cent of ore minerals. Less than 100 yards northeast of the end of this arm of the lake is a cut 8 feet wide, 10 feet deep, and 25 feet long. The best ore seen along this shore occurs there, but there is a rapid alternation of good and bad ore, so that the average of the rock as obtained in mining would be rather lean.

Exposures of highly magnetitiferous gabbro grading into ore occur on the peninsula between the two arms of Tucker Lake and along the north shore of the southern arm to the narrows, draining a small lake that lies to the east and is known as "The Pond." The nature of these outcrops is the same as those on the north shore of the north arm of the lake. The ore bodies, wherever their width is exposed, are narrow, usually not more than 12 feet in width, and their length is not more than 100 to 200 feet, being considerably less in most cases. Where their limits are not exposed on account of the drift covering, in most cases other outcrops of gabbro near by show that their size is no greater. On account of the dark-colored gangue minerals, hand specimens always appear much richer than is actually the case; and specimens of seemingly good ore are seen on polished surfaces to be rather lean. Apatite is abundant in some of these ores. Analyses at different depths of a diamond-drill core through one of these ore bodies showed the following composition of the ore:

Results of analyses of diamond-drill core from the NE. ¼ NE. ¼ sec. 2, T. 64 N., R. 3 W.

Depth	30 feet.	60 feet.	100 feet.	150 feet.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Iron peroxide	35.00	35.14	35.00	33.71
Iron protoxide	32.92	32.28	32.28	33.41
Alumina oxide	.51	.48	.40	.26
Manganese oxide	2.86	2.89	2.26	2.12
Chromium oxide	.06	.08	.012	.01
Vanadium oxide	Trace.	Trace.	Trace.	Trace.
Magnesia carbonate	1.20	1.25	1.82	1.16
Calcium carbonate	2.16	2.07	2.24	1.14
Phosphorus	.012	.012	.008	None.
Sulphur	.01	.008	None.	None.
Titanic acid	1.25	1.28	.616	.17
Silica	24.00	24.50	26.00	26.00
Metallic iron	50.50	50.00	50.00	50.00

The titanium in these analyses is very low, the average being 0.83 per cent TiO_2. This is not representative of the ore in this vicinity, however, as polished sections show considerable ilmenite. The average iron content in terms of metallic iron is 50.13 per cent. Some of this iron occurs in the femic minerals of the gangue and is not present in the ore minerals. The maximum percentage of magnetite the ore could contain is that corresponding to the percentage of iron peroxide given in the analyses. Assuming all of the peroxide of iron to be present in the form of magnetite, the percentage of iron contained in the magnetite would be 36.75, 36.90, 36.75, and 35.40 per cent, respectively, an average of 37.20 per cent.

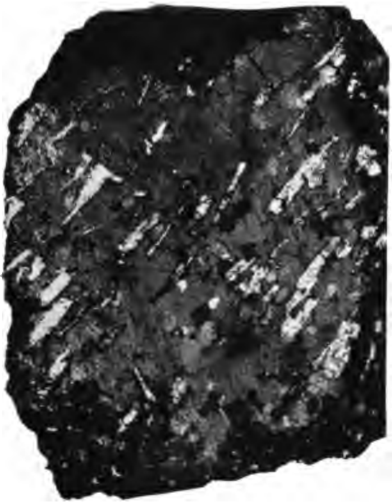
At the eastern end of the series of outcrops being discussed, along the shore of the narrows mentioned above, is a ledge of rock 300 feet long, at the eastern end of which is a small pit about 10 feet deep. The western end of this outcrop consists of the normal coarse-grained gabbro; toward the east increasing amounts of magnetite occur, until the richest ore is encountered at the pit. This ore differs from the ore previously described in that the feldspar and ferromagnesian minerals are present in the same ratio as in the normal gabbro. The change in composition of the rock is due wholly to the increase in percentage of magnetite. The feldspar has assumed, however, a distinct tabular habit, giving the rock a coarse diabasic texture. There is also a tendency to parallel arrangement on the part of the feldspar crystals which gives the rock a schistose appearance in places. Very little good ore occurs here and most of it is too lean to be called ore. A thin section of the ore showed feldspar and femic minerals about equally abundant. The femics are augite and olivine with a little biotite. The biotite seems to be principally secondary, occurring around the edges of the magnetite grains.

This series of outcrops crosses the narrows and continues eastward south of "The Pond" nearly to the line between range 2 and range 3, beyond which the gabbro contains little iron. Outcrops of ore bearing gabbro are numerous, but the extent of each is limited. The prevailing ore is of the feldspathic variety last described, though many outcrops are of better grades. High-grade ore occurs only as narrow seams and stringers in the lean ore. A thin section of the rich ore consisting of about one-third gangue had olivine as the most abundant gangue mineral; it also had considerable augite. Besides these, a little plagioclase and a few flakes of mica were present. In the leaner phases, however, the most striking feature is the tabular crystals of plagioclase. This ore differs decidedly from the Rhode Island ore with its phenocrysts of tabular feldspar. The groundmass is of much coarser grain, so that the feldspar and other constituents are more nearly of the same order of magnitude; and the feldspar crystals are far more numerous, giving the ore a pronounced diabasic texture, which the Rhode Island ore does not possess. The only ore resembling it is that from Iron Mountain, Colo.; but in the latter the feldspar is not so prominent nor the diabasic effect so marked. Plate VIII, *A*, shows a rich piece of this Iron Lake ore with the large tabular crystals of feldspar; Plate VIII, *C*, shows the Iron Mountain ore in which the feldspar tablets are more abundant, but smaller. Analyses of different sections of a diamond-drill core through a body of this ore showed the following composition:

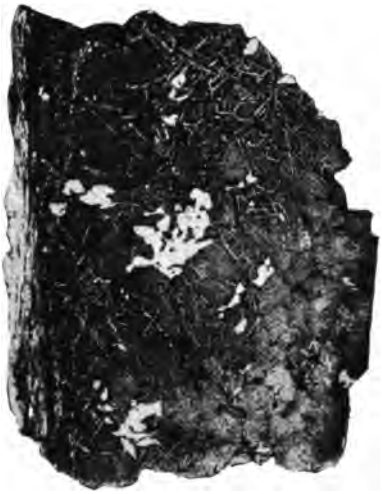
Results of analyses of diamond-drill core from the NE. ¼ NE. ¼ sec. 1, T. 64 N., R. 3 W.

Depth	55 feet.	65 feet.	75 feet.	85 feet.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Iron peroxide	35.61	46.14	35.14	41.43
Iron protoxide	30.00	21.53	32.40	24.05
Alumina oxide	2.70	4.89	4.00	2.20
Manganese oxide	1.75	2.60	3.20	.20
Chromium oxide	1.11	1.01	2.05	1.50
Vanadium oxide	1.006	.906	1.03	2.60
Magnesia carbonate	1.70	1.20	.06	1.54
Calcium carbonate	2.50	.056	.04	.05
Phosphorus	.002	.007	.002	.002
Sulphur	.006	None.	None.	.003
Titanic acid	6.50	None.	8.25	5.75
Silica	17.11	21.65	13.81	20.67
Metallic iron	49.20	49.30	48.40	48.20

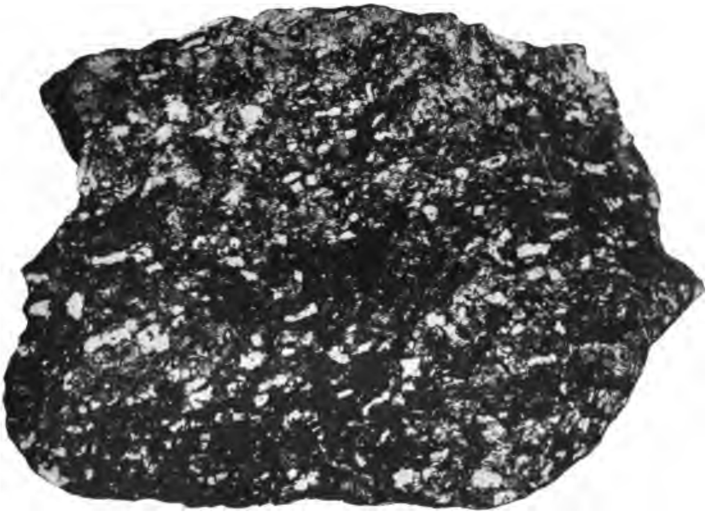
The titanium content is rather low, the average TiO_2 content of the four analyses being 5.13 per cent. The average of the metallic iron given in the analyses is 48.78 per cent. It must be remembered,



A. IRON LAKE, MINN., ORE. (X 1½.)



B. POPLAR LAKE, MINN , ORE. (X 2.)



C. IRON MOUNTAIN, COLO., ORE. (NATURAL SIZE.)

however, that some of this iron is present in the ferromagnesian gangue minerals. If we assume all the peroxide of iron to be present in the form of magnetite, the metallic iron contained in the magnetite would be 37.39, 48.45, 36.90, and 43.50 per cent, respectively, an average of 41.56 per cent.

IRON LAKE.

In addition to the ore outcrops just described, at the western end of Iron Lake and along the south shore toward that end there are others farther east along the lake, but only one or two of these is here described.

Extending across a small island southeast of the portage from Loon Lake is a band of ore 200 yards long and 20 to 30 feet wide. Gabbro is exposed on both sides of the ore body. The ore is for the most part lean. Along the north shore, east of the outlet, is a series of outcrops of ore. Some of these show very good ore, but each is of small size, passing within short distances into gabbro. One of the larger of these outcrops was traced for over 200 yards, but its width averaged only 12 to 15 feet. Even the high-grade ore contains inclusions of lean ore and gabbro; and, in other cases, the rock consists merely of gabbro with numerous bands and stringers of ore running through it. A specimen of the high-grade ore from this locality analyzed 53.30 per cent Fe, 24.30 per cent TiO_2.[a]

PORTAGE LAKE.

On Portage Lake little ore was observed. The most prominent outcrop is on the north shore of the north arm of the lake, east of the portage from Iron Lake. At this point there can be traced, for a distance of about 100 yards, a series of small ore outcrops within an area of gabbro. The ore is of the feldspathic variety and contains considerable gangue.

POPLAR LAKE.

Outcrops are abundant along the entire north shore of Poplar Lake, and many exposures of ore were seen. In all cases where the exposures were continuous enough the ore bodies were seen to be of small size. The character of the ore showed considerable variation from place to place. In some exposures the feldspathic ore occurred, in others the ore with the femic minerals. Thin sections showed considerable apatite throughout the ore, and some of the crystals of apatite are large enough to be easily recognized in the hand specimens. In addition to the ore bodies, the gabbro along this shore contains considerable magnetite scattered through it as an accessory constituent.

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[a] Analysis computed from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines.

COMPOSITION OF THE ORE.

The ore has been described with sufficient detail in the discussion of its occurrences, so that only a brief résumé is here given. Probably the most striking feature of the ore is the great variation it presents both in appearance and composition. The high-grade ore with little gangue tends to be compact and massive, rather than granular. Of the leaner ores, there are the two varieties that can be designated according to the most prominent gangue minerals, the feldspathic and the femic. The femic ores are medium grained and possess no marked characteristics. The feldspathic ores tend to be somewhat coarser grained and are characterized by the coarse diabasic texture produced by the lath-shaped feldspar crystals.

A most interesting feature is the chemical composition of the ore, on account of the unusual behavior of the titanium content. The available results of analyses are tabulated below:

Results of analyses of Minnesota ores.

Constituent.	1	2	3	4	5	6	7	8	9
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	58.48	56.16	55.04	49.83	52.46	23.50	41.12	51.40	53.30
TiO_2	20.15	0–10	4.17–31.67	16.03	2.23	2.48	36.77	14.73	24.30
SiO_2	2.02	2.40	6.20	11.37	20.90	65.17	5.19	6.08	
Fe_3O_4	80.78			53.33	70.29	30.06		71.00	
Fe_2O_3									
FeO				14.42	2.01	2.23			
Al_2O_3	2.68		8.85	1.32	1.75	Trace.	2.95	3.82	
Cr_2O_3	2.40								
Mn_2O_3		.57	.40						
CaO	Trace.	.04	.15	.10	Trace.	Trace.	Trace.	1.69	
MgO		1.35	2.28	2.73	2.63	Trace.	.35		
NiO								2.65	
P	.013	.003	.003	.01			None.		
S		Trace.	.876	Traces.	None.			Trace.	
				99.31	99.81	99.94			

Constituent.	10	11	12	13	14	15	16	17
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Iron peroxide	35.00	35.14	35.00	33.71	35.61	46.14	35.14	41.43
Iron protoxide	32.92	32.28	32.28	33.41	30.00	21.53	32.40	24.05
Alumina oxide	.51	.48	.40	.26	2.70	4.89	4.00	2.20
Manganese oxide	2.86	2.89	2.26	2.12	1.75	2.60	3.20	.20
Chromium oxide	.06	.08	.012	.01	1.11	1.01	2.05	1.50
Vanadium oxide	Trace.	Trace.	Trace.	Trace.	1.006	.906	1.03	2.60
Magnesia carbonate	1.20	1.25	1.82	1.16	1.70	1.20	.06	1.54
Calcium carbonate	2.16	2.07	2.24	1.14	2.50	.056	.04	.05
Phosphorus	.012	.012	.008	None.	.002	.007	.002	.002
Sulphur	.01	.008	None.	None.	.006	None.	None.	.003
Titanic acid	1.25	1.28	.616	.17	6.50	None.	8.25	5.75
Silica	24.00	24.50	26.00	26.00	17.11	21.65	13.81	20.67
Metallic iron	50.50	50.00	50.00	50.00	49.20	49.30	48.40	48.20

Of these analyses the average Fe content is 49.23 per cent and the average TiO_2 content 10.96 per cent. The average titanium content is somewhat lower than the average for titaniferous magnetites. It would be fairer, however, to take an average of analyses 10, 11, 12, and 13 and count that as one analysis, and the same with 14, 15, 16, and 17, as they represent only different parts of a drill core. If the analyses are averaged on this basis, there is practically no change in the iron, but the average titanium content becomes 13.23 per cent TiO_2, a percentage that is more nearly the normal. The unusual feature of this ore is the wide range shown by the titanium. In general, the titanium present in a given deposit is fairly constant. In the case of these ores, the percentage of titanic acid ranges from zero to nearly 37 per cent. Phosphorus is present in the form of apatite in considerable amount locally, but averages low. Another point of note is the absence of spinel in the thin and the polished sections examined.

METALLOGRAPHIC DESCRIPTION OF THE ORES.

Polished sections of the ores show considerable uniformity as regards the intergrowth of magnetite and ilmenite. Otherwise, as one would expect from the description of the ores, there is considerable variation. As is generally the case, polished sections of the femic ores show more gangue than is apparent in the hand specimens; and there is every gradation from pure ore wholly lacking in the essential constituent in the gabbro to rock that can be called nothing more than magnetite-bearing gabbro.

The ratio of magnetite to ilmenite also varies from ore in which ilmenite is almost lacking to ore in which magnetite is almost lacking.

The characteristic of most of the polished sections is the minute association of the titanium in the magnetite with the magnetite. Very little dull-black magnetite occurs. Most of it shows a dull-gray mottled effect to a bright iridescent effect. These effects pass over, however, by gradual transitions, to minute networks, and these into coarser networks. Also by increasing the magnification sufficiently seemingly continuous iridescent surfaces can be resolved into a close minute network of ilmenite against a black background of magnetite. Plate VII, *B*, shows an area of gangue and one of magnetite with ilmenite intergrowths. Adjacent to the gangue area, the ilmenite is so closely intergrown as to form a nearly continuous bright surface. This passes over into a delicate network. Plate IX, *A*, shows a well-developed minute delicate network, which with less magnification gives the magnetite grain a semilustrous appearance.

Though these minute intergrowths are the prevailing ones, other forms also occur. Some of the sections show beautifully developed network of the normal coarseness. Others show very coarse open network passing over into areas containing only isolated thick lamellæ. Plate VIII, *B*, shows an ore of an unusually coarse network. The thin border of ilmenite about the outline of magnetite grains, as illustrated in Plate IV, *A*, also occurs.

POSSIBILITIES OF UTILIZATION.

Deposits of titaniferous magnetite are very numerous in northeastern Minnesota, but as a general proposition it may be stated that the high-grade deposits are too small and the large deposits too lean to work.

To utilize the large deposits magnetic concentration would be necessary, but the nature of the ore is such as not to promise satisfactory results. From deposits in which nearly all of the ore consists of ilmenite, considerable titanium could be removed, but the concentrates would form only a small part of the original material. The ore of other deposits in which the magnetite forms a considerable percentage of the ore is usually swarming with the minute inclusions of ilmenite just described. Any considerable diminution of the titanium content in such ore is out of the question. Below are presented results of a separation made of a specimen showing only few grains of ilmenite and bearing magnetite that exhibited the dull, mottled, and bright iridescent surfaces characteristic of the ore from the Iron Lake region.

Results of magnetic concentration of Iron Lake ore.

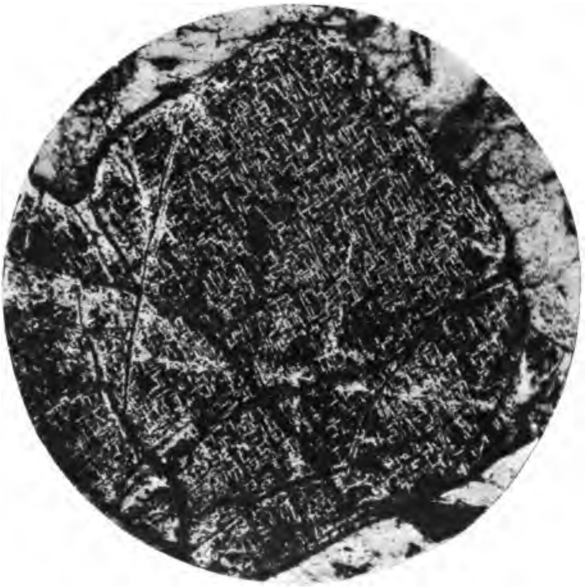
	Unscreened ore.	Ore through 50-mesh, over 100-mesh.[a]		Ore through screen finer than 100-mesh.[b]
		Magnetic.	Non-magnetic.	Magnetic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity	....	93.3	6.7	92
Fe	53.30	54.93	30.59	54.13
TiO_2	24.30	23.15	40.37	23.58

[a] 38.5 per cent.

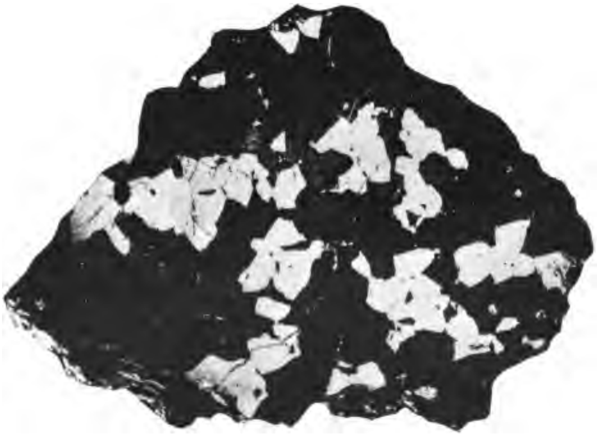
[b] 61.5 per cent.

These results confirm the intimate relation of magnetite and ilmenite brought out by the metallographic study.

In addition to the disadvantages of these deposits already mentioned, their inaccessible location must also be taken into consideration.



A. TUCKER LAKE, MINN., ORE. (X 60.)



B. IRON MOUNTAIN, WYO., ORE. (X 2.)

WYOMING.

IRON MOUNTAIN.

Iron Mountain is situated in the southeastern part of Wyoming, 20 to 25 miles northeast of Laramie and 9 miles west of Iron Mountain, on the Colorado & Southern Railroad. A second similar, but smaller, deposit occurs on the Shanton ranch, about 5 miles to the southwest. The two localities can be reached by taking the Sibylee stage from Laramie and stopping at Wayside. The Shanton occurrence lies about 3 miles from Wayside, and Iron Mountain about 8 or 9 miles, by trails which are easy to follow. Iron Mountain can be as readily reached from Iron Mountain station.

The occurrence of magnetic iron ore at Iron Mountain has been known for a great many years, and numerous accounts, more or less complete, have been given of the deposit.

Stansbury [a] as early as 1853 mentioned the occurrence of immense numbers of rounded black nodules of magnetic iron ore which seemed of unusual richness in the bed of Chugwater Creek and on the side of the adjacent hills.

In 1870, Hayden [b] called attention to the deposits in the following words:

> Near the sources of the Chugwater are some very rich iron mines, which may prove of great value to the country in the future. The fact of their existence has been known for some years, but no definite knowledge of them has been given to the world. * * *. In the winter of 1859–60, while attached to the exploring expedition of Gen. W. F. Raynolds, I made a trip to the sources of the Chugwater, and found great numbers of these worn masses of iron ore; but not until a comparatively recent period were they traced to their source in the mountains. During the construction of the Union Pacific Railroad some of the engineers visited the mines and spoke of their future value. In the summer of 1868 I had an opportunity of examining this region in company with Dr. Latham and Judge Whitehead, of Wyoming, and found the mines much richer and more extensive than had previously been supposed. We commenced our examination in the valleys of the smaller branches of the "Chug" as they emerge from the mountains, and found that the stray masses of iron ore were confined to one of them. Following the branch up into the range we soon came to the ore beds themselves, which we found to be interstratified among the red feldspathic granites which compose the nucleus of the range. The ore beds incline in the same direction with the granites, and have the same joints and cleavage, and the examples of slickensides are numerous. They are not continuous, and are confined to a restricted area, yet Mr. Whitehead traced one of the beds a distance of over 1½ miles. The ore is located much like that in the Lake Superior region, and is probably of the age of the Laurentian rocks of Canada. The quantity of ore in this locality appears to be unlimited. Thousands of tons have been washed down into the valley of the "Chug" and distributed among the superficial drift. As we leave the ore beds themselves these stray masses are larger and more angular, and as we pass down the "Chug" they dwindle to minute pebbles

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[a] Stansbury, Howard, Exploration and survey of the valley of the Great Salt Lake of Utah, Washington, 1853, p. 266.

[b] Hayden, F. V., Preliminary report of the United States geological survey of Wyoming and portions of contiguous territory, 1870, p. 14.

and disappear. Mr. J. P. Carson, of New York, an assistant in the survey of 1868, made the following analysis of this ore, at the school of mines, Columbia College:

Sesquioxide of iron	45.03
Protoxide	17.96
Silica	.76
Titanic acid	23.49
Alumina	3.98
Sesquioxide of chromium	2.45
Sesquioxide of manganese	1.53
Lime	1.11
Oxide of zinc	.47
Magnesia	1.56
Sulphur	1.44
Phosphorus	Trace.
	99.78
Fe	45.49

King[a] briefly refers to and Hague[b] describes the occurrence of a gabbro consisting essentially of labradorite and diallage which protrudes the granitoid rocks in the form of low irregular-shaped domes and knolls east of Iron Mountain and Chugwater and Horse Creeks. A microscopic description of this rock is given by Zirkel.[c] Hague does not seem to have realized, however, that this rock forms the wall rock of the ores, as he describes the deposit as follows:[d]

> Iron Mountain, to which reference has already been made, is a mass of titaniferous iron, or ilmenite, and is situated just north of the Chugwater Creek, about 1½ miles above the point where the stream leaves the hills. The mountain rises about 600 feet above the stream bed, is irregular in form, but has a somewhat oval-shaped outline. It occurs intercalated in the granite, standing nearly vertical, with the walls in places sharply defined; this is the case in the canyon, where the dark iron body resembles a broad dike, which rises to the top of the canyon wall. Frequently large masses of granite are nearly incased in the iron, and again the iron body puts out into the surrounding granite. The main deposit of iron is nearly a quarter of a mile in length, with a strike a little to the west of north and east of south. To the north the main deposit terminates somewhat abruptly; but southward it crosses the canyon, and may be traced cropping out through the granitoid rocks with the same general strike for nearly 2 miles, in the direction of Pebble Creek. These outcrops vary much in size, mostly mere narrow seams and small irregular patches of iron, which disappear in the surrounding granite. Still farther to the south, just above Horse Creek, considerable deposits again make their appearance, but much smaller than Iron Mountain, and, like the latter, have been held for valuable mineral bodies; they are probably only a continuation of the larger one. The ilmenite occurs chiefly as a compact massive deposit, iron-black in color, with a submetallic luster. It is frequently found, however, with a coarse granular structure. It is accompanied by small amounts of magnetite and hematite, which decompose and give portions of the mass a brownish-red appearance. Prof. O. D. Allen, of Yale College, examined specimens of the Iron Mountain ore, and found it to contain a mixture of ferrous and ferric oxide, which gave 50.83 per cent of metallic iron, combined with 23.32 per cent of titanic acid.

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[a] King, Clarence, United States geological exploration of the 40th parallel, vol. 1, 1878, p. 27.

[b] King, Clarence, op. cit., vol. 2, 1877, p. 13.

[c] King, Clarence, op. cit., vol. 6, 1876, pp. 107-109.

[d] King, Clarence, op. cit., vol. 2, 1877, pp. 14-16.

Other samples of the ore, analyzed by Prof. Richards, of the Institute of Technology in Boston, gave the following results:

Ferrous oxide	24.55
Ferric oxide	48.97
Titanic acid	23.18
Sulphur	.03
Residue insoluble in acid	2.15
	98.88
Metallic iron	53.33

Samples of the coarse granular variety, collected from the deposits south of Iron Mountain, yielded Mr. R. W. Woodward the following:

Metallic iron	34.29
Titanic acid	49.47

All the samples examined gave a very high, although a varying, amount of titanic acid.

This high percentage of so refractory a substance as titanic acid renders the vast deposits of iron of but little use for practical purposes in iron smelting, which is to be regretted, as the beds in the Laramie Hills could be easily mined, and are so well located in reference to a market and the known resources of iron in Wyoming are so limited.

An account in the Tenth Census is quoted direct from Hayden's description.[a]

The next mention of the deposit is made by Knight,[b] who gives the following results of analysis:

Results of analysis of Iron Mountain ore.

	Per cent.
SiO_2	1.21
TiO_2	22.43
Fe_2O_3	47.21
FeO	25.80
S	1.14
	97.79
Fe	51.72

Kemp[c] reviews the information available in 1899. Commenting on Hague's description, he says that the relations strongly suggest an intruded origin, and that "granite is an unusual wall rock for titaniferous magnetites, but gabbro, it is interesting to note, occurs in the immediate vicinity." He also mentions a rock obtained from Prof. Knight labeled the wall rock of the titaniferous ores which in thin section is a typical gabbro consisting mostly of labradorite[d] and says: "Olivine gabbro would be a much more natural wall rock than granite, and if it is the wall rock in some of the exposures, it would establish the kinship of the ore with the gabbro, and kinship that anyone familiar with the ores of this type would at once believe and assume." Kemp further calls attention to the notable percentage of zinc in the ore as determined in Carson's analysis cited by Hayden, and compares it with the Rhode Island ore in this respect. Lindgren[a] also calls attention to the fact that the presence of zinc is unusual in titanomagnetites.

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[a] Tenth Census, 1886, vol. 15, p. 485.

[b] Knight, W. C., Bull. 14, Univ. of Wyoming Exp. Station, 1893, p. 177.

[c] Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, pp. 352-355.

[d] Hill, B. F., Notes on a set of rocks from Wyoming collected by Prof. Wilbur C. Knight, of the University of Wyoming: Sch. of Mines Quart., vol. 20, 1899, p. 364.

Lindgren's paper contains the first definite statement of the character of the deposit, and the next four paragraphs are quoted from it.

> Most of the deposits of titanic iron ore form irregular masses or fairly sharply outlined streaks in gabbro, or still more commonly in anorthosite (labradorfels). Distinct dikes, undoubtedly indicating separate igneous injection of molten magma of titanic iron ore, have, however, also been described by Kemp from the Calamity Brook district in the Adirondacks, and by Vogt from near Ekersund, Norway, and the locality in Wyoming is chiefly interesting as belonging to this type.
>
> The rocks prevailing here are chiefly Paleozoic limestones and sandstones, in rolling folds, and these continue for 6 or 7 miles up Chugwater Creek. The dips here become steeper and the underlying pre-Cambrian rocks appear. As far as my observations went they consist exclusively of a labradorite rock of coarse grain which forms rough gray outcrops. The rock can scarcely be called a gabbro, for the pyroxene grains are very sparingly distributed. It contains very little magnetite or ilmenite. Going up 1 mile farther, the chief deposit is encountered; it crosses the canyon of the Chugwater as a solid dike 100 to 200 feet wide, and can be seen extending up several hundred feet in elevation on both sides of the creek. The mass is said to be traceable for half a mile north and south of Chugwater Creek. The amount of iron ore in sight is most remarkable. The contacts are not exposed to the best possible advantage, but have the appearance of being sharp and well defined. The black titanic iron ore seems entirely pure and free from accompanying minerals; at least a search along the base of the outcrop revealed no other constituents of the mass.
>
> About 400 feet below the main deposit there is exposed on the southern wall of the canyon a smaller dike only about 10 feet wide. The contacts are well exposed and show a medium-grained gray labradorite rock abutting sharply against the dike of titanic iron ore. The dike does not continue on the north side of the canyon, the bottom of which is filled with considerable débris. The greater part of the width of the dike is composed of massive titanomagnetite; but adjoining the western contact the iron ore for a width of 1 or 2 feet contains large, imperfect crystals of olivine embedded in a cementing mass of the black mineral. This association of olivine and titanomagnetite is somewhat unusual; Prof. Vogt, in fact, declares that it is not known to occur (Z. f. Prakt. Geol., 1900, p. 292) in the differentiated ores. The black mineral immediately adjoining the olivines contained, upon qualitative test, a large amount of titanium.
>
> Evidently the points where Mr. Hague saw the deposits were not the same as the locality here described, for the dike, as noted, extends over a considerable distance. The only granitic rock observed at the place described was a small, dikelike mass of fine-grained biotite granite on the north side of the canyon, nearly opposite the smaller dike of iron ore.

On November 21, 1904, Kemp presented an abstract of a paper on "The Titaniferous Magnetite in Wyoming"[b] before the New York

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[a] Lindgren, W., A deposit of titanic iron ore from Wyoming: Science, vol. 16, 1902, pp. 984-985.

[b] Amer. Geol., vol. 25, 1905, p. 64.

Academy of Sciences, which appeared the following winter in the Zeitschrift für praktische Geologie.[a] This paper agrees substantially with the views expressed by Lindgren and describes the occurrences in greater detail. The following abstract gives the essential features of the paper:

The geology of the region is roughly indicated in figure 1. The anorthosite belt extends in a northeasterly direction for a distance of nearly 20 miles without showing any appreciable variations. A plagioclase of the composition bytownite-labradorite makes up almost the entire rock. As accessory constituents occur monoclinic pyroxene, a little hornblende, some chlorite, a little calcite, and a few grains of titaniferous magnetite. The anorthosite is cut by granite dikes of granophyric texture, which seem to be somewhat more resistant to erosion and stand out at a height of about 1 meter above the anorthosite. Two such dikes cut the ore body on Iron Mountain. One of these is a biotite granite consisting of microcline, quartz, biotite, and a little plagioclase. Titaniferous magnetite occurs at two localities. One of these is at the Shanton ranch, about 6 miles southwest of Iron Mountain, where the ore outcrops in the form of a black wall above its surroundings. The largest ore body has a length of 500 meters and a width varying from 25 meters to zero, with an average width of 6 meters. The analysis made by Woodward and cited by Hague may be of a sample from this occurrence.

A careful examination of the outcrop failed to reveal any mineral other than the magnetite, which shows a smooth polished surface as a result of the sand and dust blown over it by the violent winds. Thin sections of the ore reveal the presence of many inclusions of green spinel, which suggests the magnetite spinelite of Routivara[b] and the mines at Peekskill on the Hudson.[c]

The most important outcrop of the ore is that at Iron Mountain, which is cut into two parts by Chugwater Creek, the larger part lying to the north of the creek and having a northwesterly strike. The ore projects as a black dam across the anorthosite, and forms the ridge of the hill for a distance of about 2 miles. The contact of ore and country rock is everywhere smooth and even slickensided and free of all transitions. The summit of the hill rises about 1,000 feet above the valleys. On the slope of the hill are two subordinate ore dikes. With the exception of the locality next described, the ore is free from all gangue minerals.

On the south side of Chugwater Creek, a short distance east of the main ore body, is a smaller dike about 15 feet wide which carries considerable olivine. The olivine occurs irregularly, but is more abundant near the periphery of the dike. No change in the character of the anorthosite is noticeable at the contact, which is well exposed here.

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[a] Die Lagerstätten titanhaltigen Eisenerzes im Laramie Range, Wyoming, Vereinigten Staaten: February, 1905, pp. 71-80.

[b] Petersson, W., Geol. Fören Förhandl., vol. 15, 1893, p. 45.

[c] Williams, G. H., Am. Jour. Sci., March, 1887, p. 197.

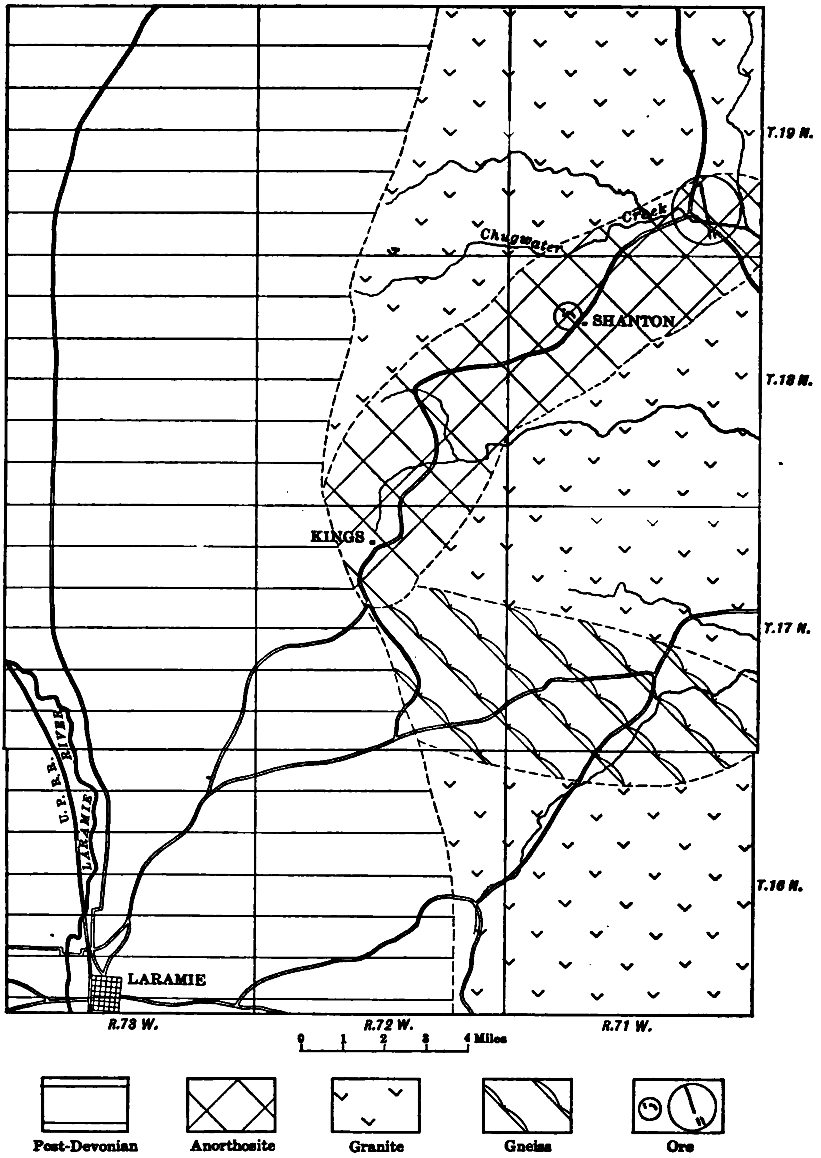

FIGURE 1.—Geological sketch of the region between Laramie and Chugwater Creek, Wyo. (after Kemp).

Though the titaniferous magnetites are usually looked upon as basic segregations, the manner of occurrence of this ore body establishes beyond doubt its intrusive character. It must be looked upon as a dike. The occurrence of such an ore body is not as surprising as might seem at first thought. Titanium plays the same rôle in eruptive rocks as silica, and these ores have an average of 23 per cent TiO_2. In other words, they are an iron titanate instead of ferromagnesian silicates.

> The chemical composition of the anorthosites is likewise significant. They contain little besides silica, alumina, lime, and soda. In a normal rock we would also expect iron and magnesium and a small percentage of TiO_2. If an original simple magma gave rise through differentiation to these two contrasting formations, which in their chemical relation are so abnormal, it was nothing less than exceptional. Therefore, it is not surprising that a titaniferous magnetite is found where the chief product is a ferromagnesian free anorthosite. Also a small iron and titanium content distributed through a large mass can through concentration bring about the formation of a very considerable ore body.

The deposit was also visited and described in 1906 by Ball.[a] He gives some data not contained in the descriptions already discussed, and these are repeated here.

Iron Mountain is described as a rugged ridge 300 to 600 feet wide and 1¼ miles long, its exact location being given by Ball as in sections 22, 23, 26, and 27, T. 19 N., R. 71 W. He says further:

> Besides this main body of the magnetic iron, minor masses occur in the pre-Cambrian rocks in a belt which is reported to extend from Horse Creek to Sibylee Creek, a distance of 20 miles. This belt, which courses a little east of north and west of south, is in places 5 miles wide. * * *
>
> The greater portion of the main deposit passed into the hands of the Union Pacific Railroad as part of the land granted to it in 1862. In 1872 a wagon road was built to the deposit, prospectors rushed in, and the whole countryside was staked. In the following year a post office, Iron Mountain, was established at the base of the Iron Ridge, but was abandoned in 1874. Eight or ten years ago the Colorado Fuel & Iron Co. employed 15 teams for several months in hauling ore from the mountains to the railroad, where it was shipped to their smelters at Pueblo. The work was suddenly abandoned, however, although the same company is reported to have made a small shipment four years ago. In 1905 and 1906 the main ore body was visited by a number of surveying corps, and the Colorado Land & Iron Co. is said to have located claims between Chugwater and Sibylee Creek.
>
> The pre-Cambrian complex near the large dike of Iron Mountain consists of three granular igneous rocks—an anorthosite, the iron ore, and a granite. The anorthosite is the oldest of these and is cut by dikes and lenticular masses of iron ore and granite. The relative ages of the iron ore and granite was not certainly determined, since exposures are poor where the two rocks are close together. All of the available evidence, however, indicates that the iron ore is older than the granite.
>
> The mass of iron ore is an igneous dike 1¼ miles long and 40 to 300 feet wide, the greatest observed width being at the point where Chugwater Creek cuts through the mass. The dike trends east of north; most of it lies north of the creek. It widens and contracts rather abruptly throughout its course. Toward the north it gradually narrows and finally disappears, while 300 feet south of Chugwater Creek it narrows slightly and then abruptly ends. At several places it is almost cut in two by wedge-like masses of granite, but throughout practically its whole length it is bordered by

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[a] Ball, S. H., Titaniferous iron ore of Iron Mountain, Wyo. Contributions to Economic Geology: Bull. 315, U. S. Geol. Survey, 1907, pp. 206-212.

anorthosite. The contact between the anorthosite and the ore, where exposed, is sharp, neither rock having undergone important gradational changes. A second dike of iron ore is exposed 300 feet downstream (east) on the south side of Chugwater Creek; this dike varies in width from 6 to 20 feet and is clearly intrusive in the anorthosite, with which it has sharp contacts. About one-eighth of a mile southeast of the south end of the main mass is a third dike of iron ore in anorthosite. The trend of this dike, which is 300 feet long and from 10 to 30 feet wide, is approximately parallel to the main mass. Several small magnetite dikes that are from 10 to 50 feet long, and have maximum widths of 3 feet, lie east of this mass in parallel alignment.

The iron ore is a black, granular, holocrystalline igneous rock, with constituent grains varying from one-eighth to one-half inch in diameter. It has a metallic or submetallic luster. Changes in granularity occur in irregular masses or along well-defined parallel planes. In consequence of this distribution the rock has at some places an original gneissic structure. The greater portion of the iron is free from mechanical impurities, but biotite, olivine, and feldspar are sporadically distributed throughout its mass. Olivine is particularly abundant in portions of the small dike 300 feet east of the main mass. The iron ore is cut by rather closely spaced joints and by slickensided fracture planes. In consequence, the outcrop is angular, and its surface is littered with square blocks broken from the ore in place.

As seen under the microscope the ore in some specimens consists principally of titaniferous iron with a little spinel. Other thin sections show considerable olivine, while biotite and labradorite are present in many specimens and in a single section a crystal of what appears to be brown hornblende was noticed.

The writer considers the iron ore and the anorthosite differentiation products of a common magma, the iron ore having been intruded in the anorthosite after that rock had completely solidified.

The above-quoted abstracts of articles by Lindgren, Kemp, and Ball show that their views as to the nature of the deposit are essentially in accord. There are a few inconsistencies in details of description. To serve as a summary of this review, a brief description of the deposits follows, based principally on the writer's own observations.

IRON MOUNTAIN DEPOSITS.

Iron Mountain forms part of the eastern edge of a pre-Cambrian area cut off on the east by Paleozoic limestones and sandstones. The prevailing rocks of the pre-Cambrian area are gneisses and granites, and these have been intruded by a large mass of anorthosite, which has itself been intruded by granitic dikes. Iron Mountain is a ridge a little over a mile long with a direction a little west of north, and an altitude of about 1,000 feet. It is made up principally of anorthosite into which has been intruded a large mass of magnetic ore, which, on account of its greater resistance to erosion, forms the summit of the ridge. The width of the ore body varies considerably, ranging from 50 to 200 feet. The ridge of the mountain is not a straight line but consists of a series of knolls which correspond to the wide parts of the ore body, such places offering greater resistance than where the ore body is narrow. The southern part of the hill is cut through by Chugwater Creek, forming a steep gorge, in the sides of which the ore body is well exposed. About 500 feet before reaching the creek the dike takes a sudden turn of 200 yards to the west and then resumes its normal strike. Plate X, *A*, shows the part of the dike south of the offset as seen from the south side of Chugwater Creek. The hill in the right background is the main ridge of Iron Mountain. The plate shows clearly the manner in which the ore projects above the adjacent rock. About 400 feet south of the creek the ore body suddenly terminates.

In thin section the anorthosite is a medium to coarse grained rock consisting almost entirely of plagioclase feldspar. As accessory constituents it contains small amounts of magnetite, biotite, and a monoclinic pyroxene. All of these minerals have been somewhat altered, giving rise to the usual secondary minerals. A little south of the center of Iron Mountain are two intrusions of a biotite granite which seemingly cut the ore body. This rock in thin section is seen to consist of microcline and quartz, with considerable orthoclase and biotite.

At the same part of the hill where the granitic intrusions occur, are three smaller ore bodies on the west slope. One of these is only 200 feet below the summit, and the others nearer the foot of the hill.

On the south side of Chugwater Creek, 300 feet east of the main dike, is a smaller dike which is characterized by an unusually large amount of olivine and plagioclase, and shows exceptionally well the contact of ore and anorthosite. Plate X, *B*, is a view of the contact here exposed. The rock on the right is normal anorthosite, which abuts directly against the iron ore without showing any change whatever. That the ore body is not a segregation in situ but an intruded body is evident from this exposure. On the left side of the plate a part of the dike is shown. Against the contact is a band of ore about 1 foot wide that contains such a large quantity of olivine that the olivine in places makes up half of the bulk. Next to this is an extremely crumbly layer about 2 feet wide. This contains, in addition to olivine, considerable plagioclase of the same gray color characteristic of the anorthosite. This part is a granular aggregate of magnetite, olivine, and feldspar, though the magnetite and olivine tend to be more intimately associated with each other than either is with the feldspar. Following this is another band consisting of magnetite and olivine, and then solid ore containing no more gangue than the main ore body. A thin section of the olivine-rich ore from this locality consisted principally of magnetite and olivine. In the magnetite were a few dark-green spinels and two small flakes of biotite. The biotite occurs intimately associated with spinel, the spinel almost surrounding and thus separating them from the magnetite. In general the ore of the main ore body is a medium to coarse grained magnetite containing little visible gangue. Locally, olivine is rather abundant, especially on the northern end of the mountain. Biotite is also widely distributed, but not in great amounts. On polished surfaces considerable spinel is seen disseminated through the magnetite, and in thin sections this is still more prominent. The crystals attain a diameter of as much as 1 mm. In one slide containing more olivine than the normal amount several small crystals of hornblende occurred in the olivine. A white crust of calcium carbonate frequently coats the ore, especially in crevices. In the northwest corner of the large outcrop on the highest point of Iron Mountain is a layer from 1 to 2 inches thick which cuts across the ore body at an angle parallel to the hill slope. This is an intimate mixture of fragments of ore and bunches of chlorite in a matrix of the white calcium carbonate.

The following results of analyses of the ore from Iron Mountain and from Shanton ranch are available:

Results of analyses of Iron Mountain ore.

Constituent.	1	2	3	4	5	6	7	8	9	10
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
TiO_2	23.49	23.32	23.18	49.47	22.43	21.75	19.47	21.85	21.08	19.98
SiO_2	.76		[a] 2.15		1.21					
Fe_2O_3	45.03		48.97		47.21					
FeO	17.96		24.55		25.80					
Al_2O_3	3.98									
Cr_2O_3	2.45									
Mn_3O_4	1.53									
CaO	1.11									
MgO	1.56									
ZnO	.47									
P	Trace.									
S	1.44		.03		1.14					
	99.78		98.88		97.79					
Fe	45.49	50.83	53.33	34.29	51.72	52.31	54.48	51.93	51.50	52.98

[a] Insoluble.

Analyses 1, 2, 3, 4, and 5 have been cited in the foregoing pages, 1 being from Hayden's report, 2, 3, and 4 from Hague's, and 5 from Bulletin 14 of the Wyoming experiment station. Kemp suggests that 4 may be from the Shanton ranch occurrence. Analyses 6, 7, 8, 9, and 10 were computed from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines. They are analyses of specimens of ore that were studied metallographically. The first three were from Iron Mountain and the last two from Shanton ranch.

With the exception of analysis 4, the analyses show considerable uniformity in the composition of the ore. Analysis 4 contains iron and titanium in almost the exact ratio in which they are present in ilmenite, but the metallographic study has failed to reveal any ores of that composition at either Iron Mountain or Shanton ranch. It

A. ORE ON IRON MOUNTAIN, WYO.

B. CONTACT OF ORE AND ANORTHOSITE, IRON MOUNTAIN, WYO.

is more likely, therefore, that the sample was obtained from some other small deposit running unusually high in titanium, and it will be left out of consideration. The average composition of the ores from both occurrences is, then, 51.38 per cent Fe and 21.84 per cent TiO_2. The titanium content is somewhat higher than the average for titaniferous magnetites. The average composition is equivalent to an ore composed of 49.84 per cent magnetite and 41.5 per cent ilmenite. With the exception of analysis 1, all the analyses are so incomplete that little further comment can be made on them. The high percentages of sulphur in analyses 1 and 5 are noteworthy, as is the unusual percentage of ZnO in 1, and the presence of several per cent of Cr_2O_3.

The contact between the ore and the wall rock is not usually exposed, but wherever the relations can be seen it is sharply defined. There is no transition from ore to wall rock. The anorthosite in contact with the ore shows the same features that characterize the anorthosite at a distance from the contact. The ore also is the same at the contact with the anorthosite as farther within the ore body. That the deposit is not a magmatic segregation in situ is evident, and the relations are such as to establish beyond doubt the intrusive character of the ore. The relations existing between anorthosite and deposits of titaniferous iron ores in other regions as in Canada, the Adirondacks, Minnesota, and elsewhere, make it most probable that the anorthosite and iron ore came from the same parent magma. Deep-seated magmatic segregation took place.' The anorthosite was intruded, and subsequently the iron ore body was intruded into it in the same manner in which the igneous dikes were intruded. The Iron Mountain deposit is therefore the analogue in basic igneous rocks of the large deposits in acidic igneous rocks, of which Kiruna, in Sweden, is the most striking example.

SHANTON RANCH DEPOSITS.

At Shanton ranch are several smaller dikes of similar character to the Iron Mountain deposit. They are situated in sec. 8 or 9, T. 18 N., R. 71 W. The geological conditions here are similar to those at Iron Mountain. The deposit lies within the anorthosite belt, which here is also cut by granitic dikes, one of which is exposed within 50 yards of the ore. The deposits occur in the midst of a comparatively level stretch of land above which they rise as small hills, the summits of which are formed by the iron ore. The relative position of the ore body is shown in figure 2. Outcrops A, B, and C are probably parts of the same ore body, though the exposures are not continuous. Outcrops D and E are smaller isolated occurrences. The width of these varies from 20 to 80 feet, the maximum width being attained by outcrop C. The relations of the ore to wall rock are the same as at Iron Mountain, and the same explanation of their origin holds.

Results of analyses of the ores have been given in the table on page 120. From these it is seen that they are essentially of the same composition as the Iron Mountain ores. Macroscopically the ores from the two localities are also identical, except that no olivine or feldspar was seen at this locality and only a few flakes of biotite. In almost all specimens any evidence of gangue minerals is lacking. On polished surfaces, however, the presence of spinel is revealed.

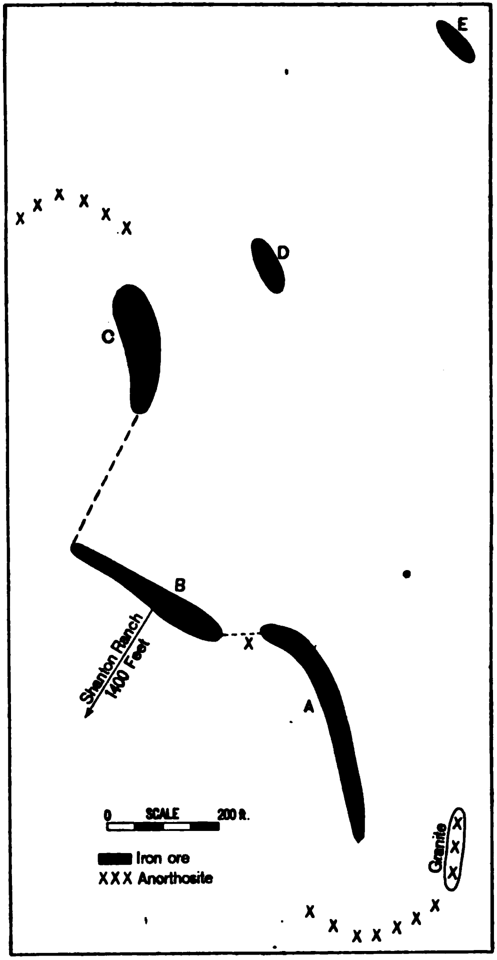
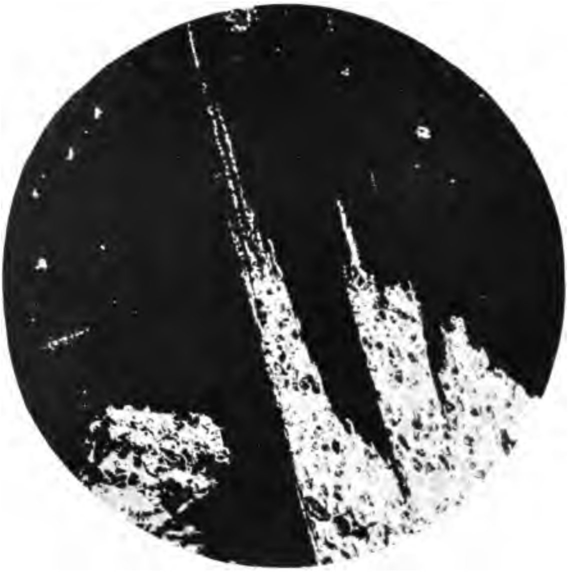


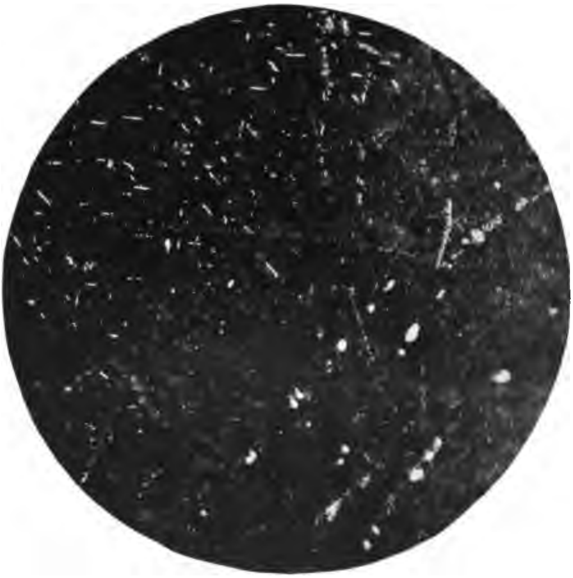
FIGURE 2.—Ore outcrops at Shanton ranch, Wyoming.

METALLOGRAPHIC DESCRIPTION OF ORE.

Etched polished sections of the ore show considerable variation. The ilmenite forms from one-tenth to one-third of the surface of the sections, types of which are shown in Plate II, *D*, and Plate IX, *B*. The ilmenite grains are nearly all about 0.25 mm. in diameter, and some areas of ilmenite have a surface of 104 sq. mm. The shape of the grains varies from approximately equidimensional to distinctly elongate. The elongate grains tend to occur in between the grains of magnetite, and may become as narrow as 0.1 mm. Some of the broader elongated grains fray out rapidly on the ends, as shown in Plate XI, *A*. Though usually following the out-



A. SHANTON RANCH, WYO., ORE. (X 60.)



B. IRON MOUNTAIN, WYO., ORE. (X 60.)

line of the magnetite grains, some of the narrow ilmenite grains take on a regular arrangement within the magnetite.

Except for a few sections in which olivine was present in considerable amount, little gangue is visible. The most prominent mineral besides the olivine is spinel. Though not present in large amount, it occurs throughout the ore in small particles. The most abundant inclusions of ilmenite in the magnetite show on the polished section as dashes and dots. The long lamellæ forming the regular linear network are almost entirely lacking, and their place is taken by the dashes which have an average length of 0.1 mm.

The dashes occur in some cases widely spaced, giving an open structure, as in a part of Plate XI, *B;* in other cases they are very closely crowded, giving a dense network effect as in Plate XII, *A*. This finally becomes so close that the effect of a somewhat continuous surface of ilmenite is produced, such as has already been described in the case of Minnesota and other ores.

The dots are in two sizes, a larger series having a diameter of about $\frac{1}{25}$ to $\frac{1}{50}$ mm. The larger dots occur irregularly distributed, or linearly along outlines of magnetite and rectilinearly parallel to cleavage directions. The irregular distribution of both large and small dots is shown in Plate XII, *B*, and XIII, *A*. The latter also shows the development of the ilmenite lamellæ. The rectilinear arrangement of the larger dots is shown in a part of Plate XI, *B*.

The minute dots occur in irregular swarms and become so minute in places as to be scarcely discernible. A great deal of the magnetite does not show a dull-black surface, but has a gray, mottled appearance. This is doubtless due to just such intergrowths, which have become too minute to be resolved with a microscope. It is shown below that a large percentage of the titanium of the ores occurs within the magnetite, a fact in accordance with the above explanation of the mottled appearance of the magnetite.

A further interesting feature noted is the abundant development of the intersecting lamellæ along certain lines in the magnetite, which seem to be the outlines of the magnetite grains. In such cases the parts of the magnetite at a distance from these lines are practically free from ilmenite lamellæ. This is illustrated in Plate XIII, *B*.

POSSIBILITIES OF UTILIZATION.

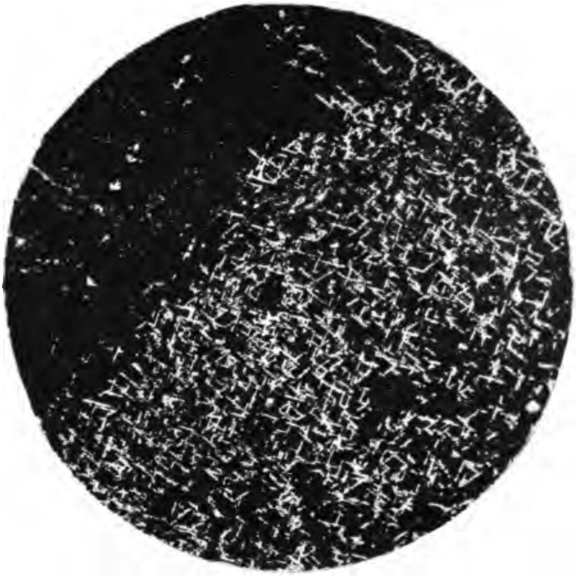
Five specimens of the ore were crushed and separated with a hand magnet. The first three were from Iron Mountain and the last two from Shanton ranch. The results follow:

Results of magnetic separation of Iron Mountain and Shanton ranch ore.

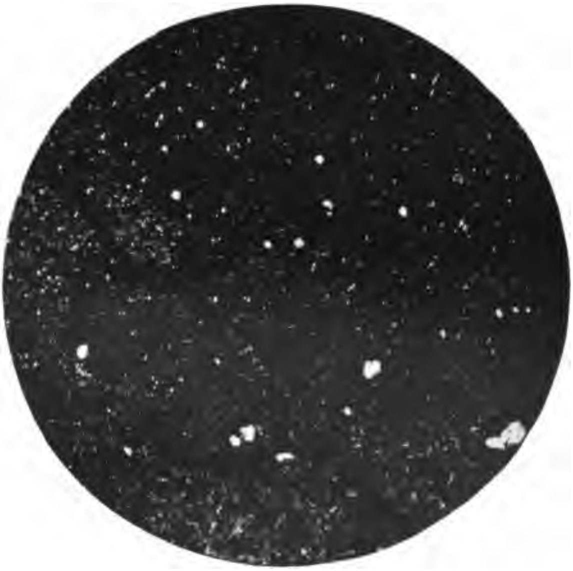
	Unscreened ore.	Ore through 50-mesh, over 100-mesh.			Ore through screen finer than 100-mesh.	
		Magnetic.	Nonmagnetic.	Proportion through screen.	Magnetic.	Proportion through screen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Proportion		84.2	15.8	48.8	83.6	51.2
Fe	52.31	56.75	28.74		56.75	
TiO_2	21.75	18.30	40.12		17.25	
Proportion		77.7	22.3	46.3	76	55.7
Fe	54.48	60.76	32.61		61.97	
TiO_2	19.47	12.58	43.47		10.32	
Proportion		87.3	12.7	46.6	86.5	53.4
Fe	51.93	55.35	28.43		55.44	
TiO_2	21.85	20.03	34.33		20.03	
Proportion		84.7	15.3	48.0	82.2	52.0
Fe	51.50	55.05	31.83		55.63	
TiO_2	21.08	17.85	38.93		17.85	
Proportion		84.1	15.9	47.5	78.6	52.5
Fe	52.98	56.93	31.96		57.30	
TiO_2	19.98	17.22	34.58		16.72	

Of these five samples the average Fe content is 52.64 per cent, and the average TiO_2 content, 20.83 per cent. Of the 50-100 mesh concentrate the average Fe content is 56.97 per cent, and the average TiO_2 content, 17.20 per cent. Of the concentrates finer than 100-mesh the average Fe content is 57.42 per cent, and the average TiO_2 content, 16.43 per cent. The average composition of the 50-100 mesh tailings is Fe 30.71 per cent, TiO_2 38.29 per cent. This corresponds to a composition of the original ore of 52.56 per cent magnetite and 39.58 per cent ilmenite; of the 50-100 mesh concentrates, 62.05 per cent magnetite and 32.68 per cent ilmenite; of the concentrates that passed through a 100-mesh screen, 63.41 per cent magnetite and 31.22 per cent ilmenite; of the 50-100 mesh tailings, 72.75 per cent ilmenite and 5.40 per cent magnetite. It is again seen that there is little advantage in grinding finer than 50-mesh. This is what one could predict from the size of the ilmenite grains, as practically all are larger than the size passing through a 50-mesh screen, and the ilmenite intergrowths in the magnetite are too minute to be separated by the 100-mesh crushing.

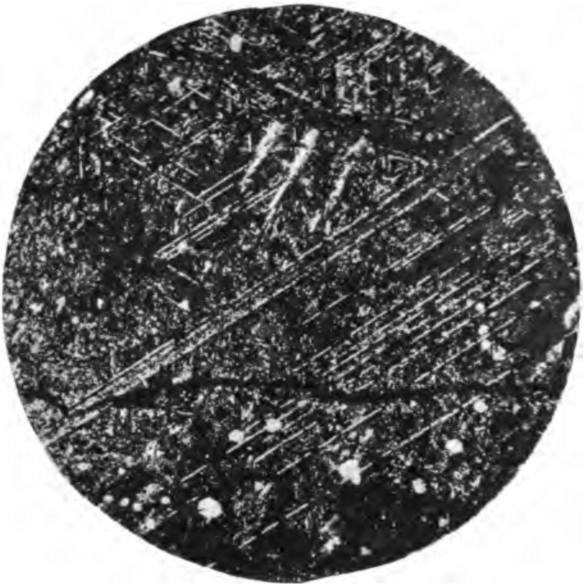
The disappointing feature is the small amount of titanium removed. A careful study of the ore, however, reveals the cause of this. Polished sections of the five specimens of ore subjected to magnetic



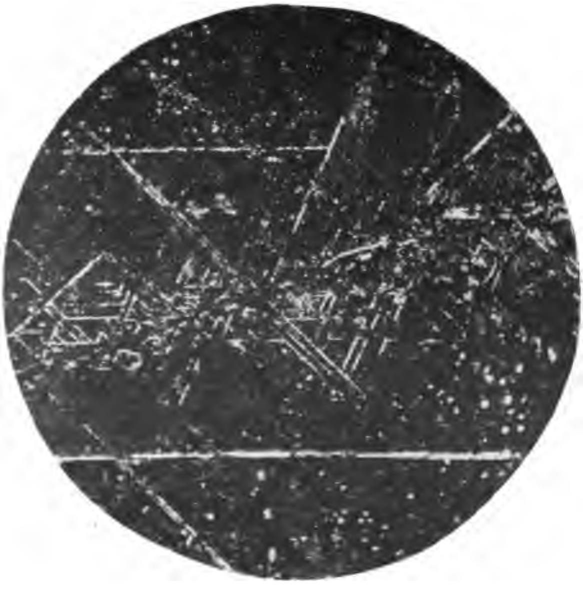
A. IRON MOUNTAIN, WYO., ORE. (X 60.)



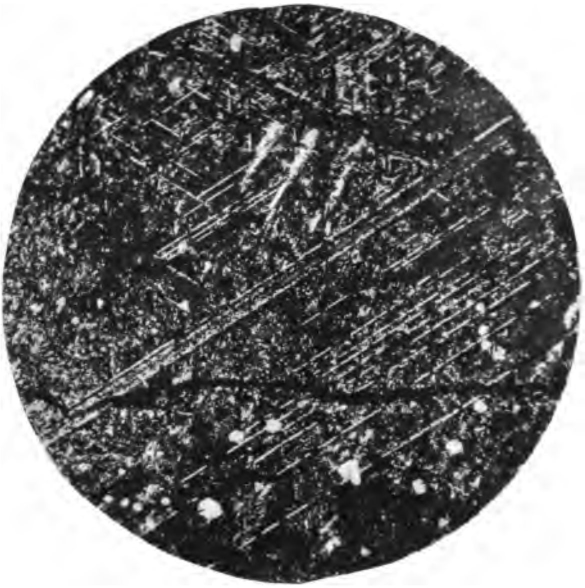
B. SHANTON RANCH, WYO., ORE. (X 60.)



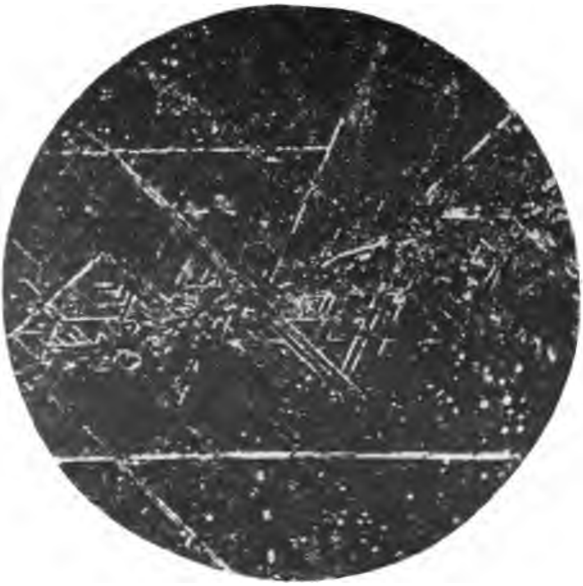
A. IRON MOUNTAIN, WYO., ORE. (X 60.)



B. IRON MOUNTAIN, WYO., ORE. (X 60.)



A. IRON MOUNTAIN, WYO., ORE. (X 60.)



B. IRON MOUNTAIN, WYO., ORE. (X 60.)

concentration were carefully measured, and it was found that ilmenite grains of separable size formed 15.3 per cent of the surface. If we calculate the titanium in the tailings in terms of ilmenite, we find the average by weight to be 12.1 per cent of the original ore. Allowing for the difference in specific gravity between magnetite and ilmenite, this is equivalent to 12.7 per cent of the original surface. In other words, 15.3 per cent of ilmenite was measured, and 12.7 per cent was separated, which is equivalent to a separation of 83 per cent of all ilmenite present in a separable condition. When the crude method of making the separation is taken into account, the result is all that could be expected.

It was shown above that 39.58 per cent of the original ore consisted of ilmenite, and that an equivalent of 12.1 per cent of ilmenite was removed. Consequently 27.48 per cent of ilmenite remained in the concentrates, which is equivalent to 69.4 per cent of the original ilmenite content of the ore. Hence the result of the separation tests was to separate 30.6 per cent of the titanium and to leave 69.4 per cent in the concentrates. It was further shown that by measurement 15.3 per cent of the ore was present in a separable condition. This was equivalent to 14.56 per cent by weight, or 36.8 per cent of the total ilmenite content of the ore; that is, only 36.8 per cent of the titanium of the ore is in a separable condition. The remaining 63.2 per cent of the titanium is so intimately intergrown and included in the magnetite as to make separation impossible. Even if a perfect separation of all ilmenite grains of separable size were obtained, there would still remain a concentrate with 13.2 per cent TiO_2 and 7.96 per cent Ti.

It is therefore apparent that it is impossible to make from this ore a concentrate low in titanium. However, the deposits are most attractive as to size and ease of mining.

COLORADO.

CARIBOU HILL.

Caribou Hill is located in Boulder County, Colo., 3 miles northwest of Cardinal Station, on the Colorado & Northwestern Railroad. The deposits of titaniferous iron ore occur on the northeastern and southeastern slopes of the hill, close to the old town of Caribou, in the Caribou or Grand Island district, where once were rich silver mines. This camp is now almost deserted and only a remnant of the town remains.

Putnam[a] collected two samples here in 1880, the analyses of which are given below, and describes the deposit as follows:

> A mass of titaniferous magnetite occurs in Caribou Hill, near the Caribou and other silver mines, in Boulder County. Caribou is 20 miles from Boulder, near the Conti-

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[a] Tenth Census, vol. 15, 1886, p. 476.

nental Divide. Its elevation above tide is 9,900 feet. Two small openings were made at the western end of the outcrop some years since, and a little ore was taken out and teamed to Boyd's smelter at Boulder. The pits are 8 to 10 feet deep and 6 to 8 feet wide. The ore exposed in them and seen on the dump varies greatly in richness, the mass being made up of little seams of rich, compact magnetite, lying in a siliceous magnetic rock. The outcrop extends along the crest of the hill, and is about 400 feet in length. The north side of the hill is completely covered with float ore. All the ore is very magnetic, and exhibits polarity to so marked a degree that the dip of the needle changes from + 90° (north end down) to – 50° (south end down) in the distance of 10 paces. There is undoubtedly a large amount of iron ore in the hill, but it is probable that the rich ore is too irregularly distributed through the rocks to permit of its being economically mined, even if other circumstances were favorable.

Chauvenet[a] spoke of the deposit in 1886 as a vein of black magnetite, and gave an analysis of the ore which is cited below. In 1890 he made the following mention[b] of the occurrence:

> Beginning with Boulder County, we have the vein in Archean rock already mentioned, which is found on Caribou Hill, close to many rich silver veins, though not itself forming part of the system of veins which carry the precious metals. This vein powerfully affects the compass in its vicinity and is called a deposit of magnetite, though, as far as analysis is concerned, it might be named ilmenite, since it contains the unusual amount of 36 per cent of titanic acid. Its percentage of iron is from 36 to 38. The ore is compact, jet black, and, of course, worthless as iron ore.

Kemp[c] also refers to the deposit briefly, saying that beyond establishing the character of the ore little has been accomplished and no determinations of the wall rock have been recorded.

A detailed account of the deposit has recently been published by Jennings.[d]

GENERAL FIELD RELATIONS.

The deposit lies in the northeastern corner of the Central City quadrangle, which has recently been mapped by E. S. Bastin and J. M. Hill, of the United States Geological Survey. A detailed description of the geology and the ore deposits of this district is now in the course of preparation by the Survey and only a brief sketch of the geology is given here.

The district is within the belt of pre-Cambrian granites and gneisses forming the Front Range. These rocks have been intruded by numerous dikes ranging in composition from acidic to extremely basic. On Caribou Hill are several intrusions of basic material, and it is within these that the ore occurs. The most important one is the dike on the northeast slope of the hill, which can be traced for over 1,500 feet. It begins at a point 500 yards west of Caribou and runs up the hill slope in a southeasterly direction for about 400 feet, where it bends sharply to the east and continues for about 1,000 feet to the edge of Caribou. A second intrusion, having more of a stock shape, occurs on the southeast slope of the hill, half a mile southwest of Caribou. A third smaller outcrop occurs near the top of the hill about 100 yards southeast of the summit. These rocks show considerable local variations, but are essentially pyroxenitic in character. Associated with the pyroxene in places is feldspar and biotite. The texture ranges from that of a coarse pyroxenite to a very fine-grained rock.

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[a] Chauvenet, Regis, Notes on iron prospects in northern Colorado: Bien. Rept. of the Colo. State Sch. of Mines, 1886, p. 16.

[b] Chauvenet, Regis, the iron resources of Colorado: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 267.

[c] Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, p. 335.

[d] Jennings, E. P., A titaniferous iron-ore deposit in Boulder County, Colo.: Bull. Am. Inst. Min. Eng., October, 1912, pp. 1045–1056.

THE ORE DEPOSITS.

Some magnetite occurs as an accessory constituent of the basic rocks, and this becomes segregated into richer pockets, forming a medium-grade ore. But even in the ore-bearing parts of the rock the composition is not uniform. It is rather a rock rich in magnetite with numerous stringers and veinlets of almost pure magnetite. The magnetite is highly magnetic and much of it is natural lodestone. These stringers of pure ore never exceed 6 inches in thickness and seldom measure more than an inch or two. They may form such a network within the leaner rock as to constitute a medium-grade ore. Such ore bodies do not reach a width of more than a foot or two or a length of more than a few feet. The ore in the pits and trenches that have been made along the western end of the dike northwest of Caribou consists of a series of closely crowded lenses of that character. The dike has a width of 50 to 100 feet or over, but only a small part consists of ore of even this grade. The ore in the other two occurrences is still leaner and there is still less of it. Thin sections of the ore show that it consists essentially of the ore minerals and pyroxene, the latter ranging in composition from diopside to augite. The pyroxene is frequently altered to serpentine, and in part to hornblende. Some biotite is also usually present. Inclusions of dark-green spinel in the magnetite are common.

The following analyses of the ore have been published. Analyses 1 and 2 are taken from the Tenth Census Report and analysis 3 from Chauvenet. Analysis 4 is calculated from the more detailed analysis by Jennings, which is also given in full.

Results of analyses of Caribou iron ore.

Constituent.	1	2	3	4
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Fe	59.04	35.35	36.93	50.97
SiO_2	....	....	1.16	9.60
TiO_2	Present.	Present.	36.76	4.48
P	.017	.022	.04	....

Mineralogical composition of medium-grade ore from northwest dike.

[Analyst, E. P. Jennings.]

	Per cent.
Ilmenite	8.50
Magnetite	67.25
Apatite	.18
Spinel	6.70
Diopside	16.89
H_2O at 105°	.51

METALLOGRAPHIC DESCRIPTION OF ORE.

A metallographic study of the ore shows little of interest. The richer veinlets consist of medium-grained aggregates of magnetite and ilmenite with a little gangue. The ilmenite is far less abundant than the magnetite and occurs in smaller grains, in many places as small particles filling interstices between the magnetite and the gangue grains. The leaner ore, which grades over into the country rock, contains scattered grains of magnetite and ilmenite, with the femic minerals in excess.

Intergrowths of ilmenite in the magnetite are not abundant. Most frequently they consist of dots and small particles scattered irregularly through the magnetite. Regular intergrowths of tabular ilmenite in the magnetite are not numerous. Altogether, the quantity of ilmenite seen in polished surfaces would not lead one to expect the high titanium content given by Chauvenet in his analysis, a conclusion that is corroborated by the analysis by Jennings presented above.

POSSIBILITIES OF UTILIZING ORE.

Titaniferous magnetite occurs in small pyroxenitic intrusions on Caribou Hill. The best of the ore is only medium grade and the ore lenses are very small. On account of its small size the deposit can never have any economic value.

IRON MOUNTAIN.

Iron Mountain is situated in the southern part of Fremont County, about 12 miles southwest of Cañon City, and 15 miles north of Silver Cliff. It lies on a branch of Pine Creek, which is itself tributary to Grape Creek, and the locality is often referred to as Grape Creek. More exactly, it is 3½ miles east of the western edge and 1 mile north of the 38° 20′ line of the Cañon City topographic sheet.

Though the deposit has been visited several times, there is little information to be had in regard to it. This is doubtless the deposit referred to by F. M. Endlich in 1873.[a] He says: "A short distance up Grape Creek Cañon a deposit of magnetic iron ore occurs, which is being worked at present." This was probably about the beginning of mining operations here, as Putnam[a] states that a United States patent for the land was obtained in 1872. During this period the ore was hauled by wagon to Cañon City by freighters on their return trips to that point. Shortly before 1880 a branch line of the Denver & Rio Grande Railroad was built up Grape Creek from Cañon City to Silver Cliff. This passed within 4½ miles of the deposit, and preliminary surveys were made for a branch line up Pine Creek to the deposit, but the line was never built; and in 1888, after a series of washouts, the Silver Cliff line was abandoned. The deposit was worked at several points, but none of the pits are large, the average being about 50 feet long, 10 to 15 feet wide, and 10 to 15 feet deep. Consequently the total amount of ore mined was not great.

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[a] Hayden, F. V., Seventh Annual Report of the United States Geological and Geographic Survey of the Territories, 1873, p. 333.

The most complete account of the deposit is given by Putnam,[b] and in his report a number of analyses of the ore are included.

In 1885 Chauvenet,[c] referring to these ores, says:

> The ore is a magnetite, not very siliceous, but containing from 10 to 15 per cent of titanic acid. Its use, even in relatively small quantity, was found extremely troublesome, and was limited to such a proportion that the entire mixture of ores charged should contain but 1 per cent of the impurity. Even at this low figure the working of the furnace was retarded. This ore yielded 45 per cent of iron and sometimes more, but the workings have been practically abandoned.

Again, in 1890, he says:[d]

> In Fremont County is the mine known as the Grape Creek. The ore is titaniferous, showing a very steady average of about 14 per cent of titanic acid. Its iron runs about 48 per cent. It is no longer used in the blast furnace, but is useful as "fix" in the puddling mill. The deposit is a large one, and it is a pity that its character prevents its more extensive use.

Kemp's account[e] is based chiefly on Putnam's, but in addition he determined a specimen of gray granitoid rock in a collection of the titaniferous ores at Columbia University to be olivine gabbro. This is the first and only information we have as to the character of the rock associated with the ore.

GENERAL FIELD RELATIONS.

The prevailing rocks of the region are granites and gneisses. These have been cut by numerous dikes, prominent among which are pyroxenite. Besides the dikes, they have also been intruded by a large mass of gabbro. The greater part of this mass forms a high hill north of the ore deposits, which is known as Iron Mountain.

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[a] Putnam, B. T., Tenth Census, vol. 15, 1886, p. 472.

[b] Op. cit., pp. 272-276.

[c] Chauvenet, Regis, Preliminary notes on the iron resources of Colorado: Ann. Rept. of the Colo. State Sch. of Mines, 1885, p. 16.

[d] Chauvenet, Regis, The iron resources of Colorado: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 270.

[e] Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, pp. 333-334.

The gabbro continues southward across a low flat spur of Iron Mountain and two small hills separated by dry arroyas. It is on this spur and the two hills that the ore deposits occur. The ore-bearing part of the gabbro takes on a more feldspathic character than that composing Iron Mountain, and in places grades over to a true anorthosite.

The gabbro is likewise cut by dikes, the most common of which are hornblende syenite with accessory zircon and magnetite. At the south end of the spur of Iron Mountain are several dikes of a dioritic rock. This location is marked A on the map constituting figure 3. One of the dikes cuts through both the gabbro and an ore segregation in it. The groundmass of the rock is a coarse granular aggregate of plagioclase feldspars of about the composition of oligoclase. Zircon occurs as an accessory constituent, and in one part of a slide is a swarm of minute isotropic grains which seem to be spinels. Green pyroxene and amphibole are prominent constituents of the rock. The crystals of these minerals are usually larger than those of the feldspar, and some of the hornblende prisms attain a length of 3 cm. and a diameter of 0.5 cm.

As stated above the gabbro varies in character from a typical olivine gabbro to one in which the ferromagnesian minerals become accessory and which approaches a typical anorthosite in composition. The most abundant ferromagnesian mineral in the gabbro is augite; less abundant but prominent is olivine. Magnetite, with numerous inclusions of green spinel, and a little biotite and hornblende are also present. The anorthositic phases contain the same minerals in subordinate amounts. A slide of this rock shows the olivine surrounded by rims of hornblende so that it usually does not come in contact with the feldspar.

THE ORE DEPOSITS.

The first hill south of the spur from Iron Mountain affords the most promising showing of ore, and it is here that most of the openings were made. This hill is 800 feet long, 500 feet wide, and 60 feet high. The locations of the principal ore bodies in it were determined by Putnam by means of a magnetic survey, and are shown in figure 3, reproduced from his map. These ore bodies are exposed at several points both in natural exposures and in the old ore pits, and the relations of the ore to the wall rock are well shown.

The distinction between what is ore and what is wall rock can generally be sharply drawn. The wall rock may be anorthosite or it may be a gabbro rich in ore minerals; the ore may be a rich magnetic ore with little gangue, or it may be a lean ore carrying large percentages of the common constituents of the adjacent wall rock. But no matter how closely the two may approach each other in composition, there hardly ever exists what one would call a gradual transition. The change from wall rock to ore is so rapid that one has no difficulty in fixing a contact.

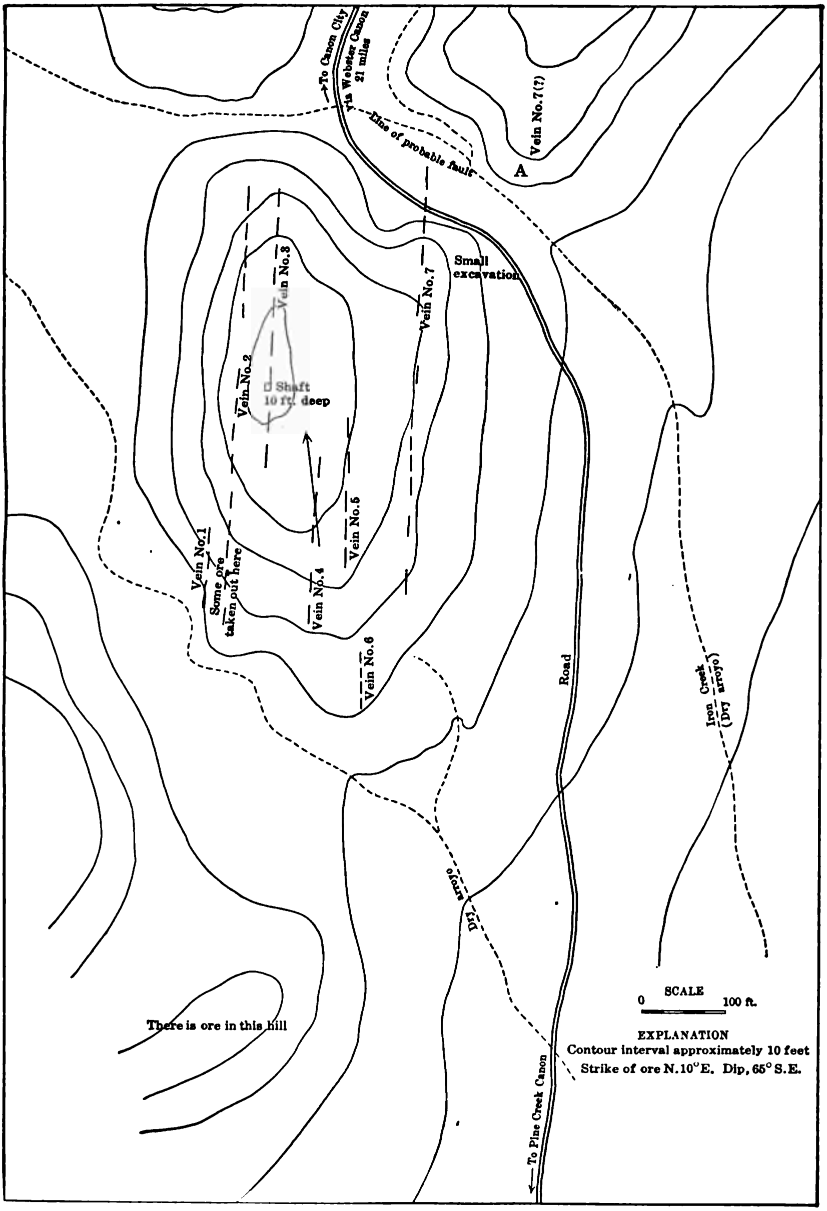


FIGURE 3.—Map of Iron Mountain, Colo. [From Tenth Census report.]

The width of the ore bodies ranges from about 10 to 50 feet, and does not average more than 25 feet. Their length can not be determined on account of lack of exposure. Whether those indicated on

Putnam's map (fig. 3) are continuous or represent zones of ore lenses is an open question. The latter supposition is the more probable.

The ore itself is rather uniform in composition and appearance. It is a compact aggregate of magnetite and ilmenite, on fresh fractures of which the ilmenite can be recognized by its higher luster. The gangue minerals are the constituent minerals of the gabbro. In some specimens the gangue is very prominent; in general, however, the ore is of good grade. The most characteristic mineral of the gangue is the feldspar. It has a tabular habit, and tends to a subparallel arrangement, which gives to the ore a striking diabasic appearance. The similarity of this ore to some of the Minnesota ore has already been mentioned. Plate VIII, *C*, shows a specimen of the ore in which the white feldspar crystals are plainly visible against the dark background of the ore minerals. A thin section of the ore consisted of nearly three-fourths magnetite in which are abundant inclusions of dark-green spinel. The most prominent gangue minerals were the lath-shaped feldspars. Olivine was less abundant and biotite only sparingly present. Along the boundary of the feldspar and olivine against the magnetite is a narrow rim of a yellowish-brown mineral which seems to be hornblende.

Several analyses of the ore have been made and they show a very uniform composition. The analyses are tabulated below:

Results of analyses of Iron Mountain ores.

Constituent.	1	2	3	4	5	6
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	48.89	48.18	46.61	48.85	46.05	47.01
TiO_2	11.99	12.92	11.61	12.73	13.84	14.86
P	.025	.026	.037	.011	.040	.039

Constituent.	7	8	9	10	11
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fe	47.42	49.35	43.4	48.79	51.96
TiO_2	13.04	14.00	10.0	....	14.5
P	.026	....	....	Trace.	....

Constituent.	8	9	10
	Per cent.	*Per cent.*	*Per cent.*
Silica	8.60	18.60	2.75
Alumina	4.00	7.00	7.70
Lime	1.60	1.30	None.
Magnesia	2.30	1.60	3.20
Titanic acid	14.00	10.00	....
Peroxide of iron	70.50	62.00	....
Magnetic oxide of iron	....	....	67.76
Sulphuric acid	....	....	Trace.
Phosphoric acid	....	....	Trace.
Oxide of manganese	....	....	Trace.
	101.00	100.50	....

Analyses 1 to 7 are taken from Putnam's report, analyses 1 to 5 representing samples taken from the ore bodies indicated on figure 3 by the numbers 2, 3, 6, 3, 4, respectively. The sources of samples represented by analyses 6 and 7 are not given. The samples represented by analyses 8 and 9 were collected by M. Chaper, and the analyses made at the School of Mines, Paris. M. Chaper, of the Geological Society of France, visited the deposit in 1875, and extracts of his report together with the analyses were published in 1877–78. The analyses as here presented are taken from Putnam's report, in which they are cited. The sample represented by analysis 8 is described as a "compact titaniferous magnetite with feldspathic gangue"; the sample represented by analysis 9 is described as "an oxidized iron sand, forming the bed of Iron Creek for several miles above Iron Mountian. A portion of the iron exists in the state of protoxide, which is all converted into peroxide, whereby the increase in weight results." Analysis 10 was made in 1871 by Charles S. Hinchman and was quoted by Putnam. Analysis 11 was calculated from analyses of concentrates and tailings made by A. C. Fieldner, of the Bureau of Mines.

The average composition of the ore is shown to be 47.86 per cent Fe, 12.95 per cent TiO_2, and the phosphorus content considerably below the Bessemer limit. The titanium content is about the average for titaniferous magnetite.

METALLOGRAPHIC DESCRIPTION OF ORE.

All the polished sections of the ores that were studied are much alike. On all of these the gangue constitutes less than one-fourth of the surface and averages about one-eighth. Ilmenite grains seldom exceed 10 per cent of the surface, and the average is below 10 per cent. Manifestly, the magnetite must contain a considerable part of the titanium.

A conspicuous feature of the magnetite is the almost complete absence of the large intersecting lamellæ of ilmenite. The most common ilmenite intergrowths are dots, which occur in great numbers. Though every intermediate size occurs, they tend to be of two orders of magnitude. The most abundant are extremely minute dots, examples of which have already been shown in the case of other deposits. (See Pl. XII, *B*, and Pl. XIII.) The larger series have a diameter which may be expressed in hundredths of a millimeter, and in places become as great as 0.1 mm. Both sizes of dots may be, and usually are, present in the same specimen. Pl. XIV, *A*, shows the large dots both irregularly distributed and in linear arrangement.

On some surfaces are seen extremely delicate networks of closely spaced short lamellæ in the midst of which are dots of the larger size. The effect is that of a minute network upon which the dots have been superimposed. This is illustrated in Plate XIV, *B*. Such a network in many places grades over into a more minute network until finally the intersecting structure can no longer be recognized even under high power. The transition is gradual enough to make certain that the disappearance is not due to the discontinuance of the network, but to the fact that it becomes so delicate as not to be discernible.

Another method of intergrowths is the occurrence of well-formed laths of ilmenite. These range from 1 to 2 mm. in length and may have a width of as much as 0.2 mm., though usually much less. This feature is shown only in a few places. It reminds one of the intergrowths of the North Carolina ore shown in Plate VII, *A*. In this case, however, the laths are smaller and much more regularly formed.

POSSIBILITIES OF UTILIZING ORE.

The structure of the ore revealed on polished surfaces is such as to make impossible the elimination of any considerable percentage of the titanium by means of magnetic concentration. Not more than one-third of the titanium occurs in grains large enough to be isolated when crushed to 100-mesh. The following results of a test on a specimen of the ore are even more disappointing than one would have expected:

Results of magnetic separation of Iron Mountain ore.

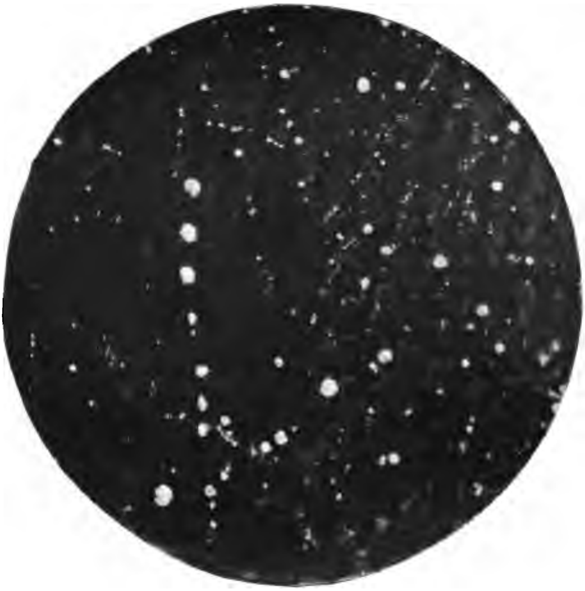
	Ore.	Ore that passed through 50-100 mesh screen.[a]		Ore that passed through screen finer than 100-mesh.[b]
		Magnetic.	Nonmagnetic.	Magnetic.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Quantity		86	14	80.4
Fe	51.96	56.93	21.42	57.77
TiO_2	14.5	13.5	20.97	13.1

[a] 46 per cent.

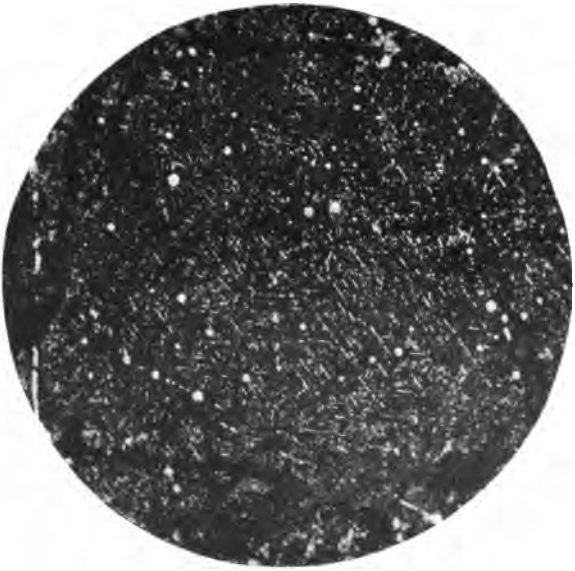
[b] 54 per cent.

Here as in other cases the separation is little better in the more finely crushed ore, owing to the fact that the ilmenite grains are nearly all larger than a 50-mesh opening and the intergrowths in the magnetite are nearly all smaller than a 100-mesh opening.

The ores have about the average composition of titaniferous magnetites, but the titanium is intergrown with the magnetite in such a manner as to make possible only a very incomplete separation of the two. Hence their utilization depends entirely upon the possibility of using ores containing 14 per cent TiO_2. But even in such an event



A. IRON MOUNTAIN, COLO., ORE. (X 60.)



B. IRON MOUNTAIN, COLO., ORE. (X 60.)

the deposit is not very promising. The individual ore bodies are not large and the total tonnage not great; also, the expense of securing proper transporation facilities would be heavy. Consequently this occurrence can not be looked upon as an important ore reserve.

CEBOLLA CREEK.

The Cebolla district is located on the east side of Cebolla Creek, south of Powderhorn, in the southern part of Gunnison County. It lies about 9 miles east of the Lake City branch of the Denver & Rio Grande Railroad, but is best reached by a stage line from Iola, on the Denver & Rio Grande narrow-gage line which lies 15 miles to the north.

The occurrence of titaniferous magnetite in this region has been known for some years, but no description of the deposit has ever been published.

J. K. Hallowell[a] visited the deposit in 1883, and said of it:

> The Cebolla iron deposit is a peculiar formation unto itself. I was asked regarding its geology. I had to weaken; I never saw anything like it or read of anything similar. There is iron enough, over a mile square of it, apparently overlaid by trachyte at one time. The country rock is granite. The ore is heavy black magnetite, of fair grade of iron, but carrying, as I was afterwards informed, * * * too much titanium to be practically available in iron manufacture.

Chauvenet[b] in a report on the iron resources of Gunnison County in 1887 makes the following mention of it:

> We come next to a region known as the "Cebolla" district, situated near White Earth Creek (usually called Cebolla Creek) and at an average distance of about 26 miles from Gunnison City. This district lies very close to a proposed extension of the Denver & Rio Grande Railroad to Lake City, Hinsdale County.
>
> An immense ledge of titaniferous iron ore exists here, but little need be said of it. Samples taken from it vary greatly in their percentage of this objectionable material, the lowest I have ever analyzed yielding 9.38 per cent and the highest 36 per cent. This last was rather to be classed as "ilmenite" than as iron ore. This deposit is enormous in extent and is well worth exploitation with a view to ascertaining whether in parts or at depth it will not yield a product lower in titanium than any yet discovered. At present it must be condemned as unfit for smelting, at least by itself.

Two years later Chauvenet again refers to the deposit as follows:[c]

> Next, as a curiosity, not as a commercially valuable mine, I would name the Cebolla Creek titanium deposit. No one knows how the ore will hold out here, but as it can be developed in many places for some miles it will last, in all likelihood, far longer than there is any use for it. It contains from 9 to 36 per cent of titanic acid. We have all read in our textbooks on chemistry that titanium is a "rare" metal. I do not think I risk much in saying that this is an inexhaustible stock of it.

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[a] Hallowell, J. K., Gunnison, Colorado's Bonanza County: Colo. Mus. App. Geol., 1883, p. 106.

[b] Chauvenet, Regis, Iron resources of Gunnison County: Ann. Rept. State Sch. of Mines of Colo., 1887, p. 18.

[c] Chauvenet, Regis, The iron resources of Colorado: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 272.

In 1896, Arthur Lakes[a] described deposits of nontitaniferous iron ore which occur in the immediate vicinity of the titaniferous iron, but made only a brief reference to the latter. He examined the small opening close to the road, directly opposite the Cebolla Hot Springs, and described the ore as "gray massive iron" which is "mingled with streaks of brown mica and a green, somewhat asbestiferous-looking mineral, which may be hornblende or pyroxene."

Kemp[b] refers to the deposit and comments on the lack of information in regard to the ore or wall rock.

In the summer of 1905 or 1906 the district was visited by Van Hise and Leith,[c] and is classed by them genetically with the Iron Springs district of Utah; that is, as a contact metamorphic deposit.

The above information in regard to this district, though meager, was of such a character as to excite considerable interest from a scientific point of view. No titaniferous magnetites of contact metamorphic origin are known to the author. Krusch[d] cites the absence of titanium as one of the characteristics of these ores, and Beyschlag, Krusch, and Vogt[e] state that experience up to the present has been that these ores are characterized by an almost complete absence of titanic acid, with an occasional trace.

Here was seemingly a highly titaniferous contact metamorphic magnetite deposit, and the author's examination of the same showed that such actually was the case for a part of the deposit. A detailed account of the geological features of the deposit has recently been published by him[f] and the geological discussion in this report is restricted to a summary of that account.

GENERAL FIELD RELATIONS.

The Cebolla district lies within a region of pre-Cambrian rocks consisting mostly of granites and gneisses. In the midst of these rocks is an area of basic igneous rocks, limestone, and rhyolitic lavas. It is in association with the basic igneous rocks and the limestone that the titaniferous iron ores occur. The basic rock contains numerous small segregations of ore. It has intruded a part of the limestone in a most intricate manner, producing products of contact metamorphism and the deposition of contact metamorphic iron ores.

---

[a] Lakes, Arthur, Iron and manganese; The great Cebolla River deposits: Coll. Eng. and Metal Miner, 1896, pp. 267-268.

[b] Kemp, J. F., A brief review of the titaniferous magnetites: Sch. of Mines Quart., 1899, p. 335.

[c] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, 1908, pp. 92, 93.

[d] Krusch, P., Die Untersuchung und Bewertung von Erzlagerstätten, 1907, p. 179.

[e] Beyschlag, Krusch, Vogt, Die Lagerstätten der nutzbaren Mineralien und Gesteine, vol. 1, 1909, p. 351.

[f] Singewald, J. T., jr., The iron-ore deposits of the Cebolla district, Gunnison County, Colo.: Econ. Geol., 1912, pp. 560-573.

ORE DEPOSITS.

MAGMATIC SEGREGATIONS.

The basic igneous rock has undergone considerable differentiation, and shows rapid variation from place to place, especially in the ore-bearing area. To the north of the ore-bearing area it consists of a dark, greenish, fine-grained rock, in which locally considerable chalcopyrite is disseminated. The leaching of this has given rise to green, copper stain in crevices of the rock, and at one such point some prospecting has been done. Within the ore-bearing area the rock is somewhat coarser grained, and especially in association with the ores becomes very coarse grained. In general the coarse-grained varieties are feldspar poor or free, though typical feldspar-rich gabbro does occur. Most of these coarse varieties consist of coarsely crystalline aggregates of pyroxene, biotite, and ore in all possible ratios.

The richer ores consist of aggregates of titaniferous magnetite and bunches of dark-brown mica which reach several centimeters in diameter. In such specimens pyroxenes are not abundant. They grade over, however, into leaner ores in which the pyroxenes are more abundant, until a rock results that consists almost entirely of pyroxene. The ores are not entirely confined to these coarse rocks, but also occur as veinlets and stringers in the adjacent fine-grained rocks. These ores were prospected and worked to a slight extent about 30 years ago by a Mr. Crooks, of Lake City, who hauled some to the smelter located there at that time. Their titaniferous character was soon discovered and further shipments were refused by the smelter. The most extensive openings were made in a draw 1 mile northeast of the Hot Springs. Another opening 50 feet long, was made just above the main road in the valley due east of the Hot Springs. Besides these, numerous smaller openings have been made, especially where the intrusions in the limestone occur. The ores throughout the area show the same features, both as to their mineralogical associations and their geological occurrence. There is no evidence of the occurrence of any large ore bodies, but rather of a large number of very small ore segregations. No analyses of the ores were made, but the metallographic study of the ores corroborates the high percentages of titanium given by Chauvenet. In almost all specimens examined the ilmenite was far in excess of the magnetite.

The composition of the ores, their mineralogical association, and their manner of occurrence establish beyond doubt their genetic position. They are magmatic segregations of titaniferous magnetites in a basic igneous rock.

CONTACT METAMORPHIC ORES.

Petrographically the area within which the limestone has been intruded by the basic rock affords a complete gradation from the basic igneous rock to a pure-white, coarsely granular marble. In some places the igneous rock has resorbed some of the limestone, so that calcite occurs in it as a primary constituent. At other places occurs limestone in which large mica flakes are abundantly disseminated. Elsewhere, typical products of contact metamorphism of limestone have been formed. The transitions are so rapid that one can pass from one extreme to the other within a few paces. The effect is that of a limestone mass that has been intricately intruded by the igneous. Sufficient time was not available to determine whether the intrusion took place in the form of a large number of distinct dikes, or in the form of irregular stocks. The complex is the least resistant of the rocks of the region, and hence has not afforded many pronounced outcrops.

The igneous rock is the same as that described above, and associated with it are small ore segregations of the character described.

The most interesting feature of this complex is the occurrence of small deposits of contact metamorphic ore. The product of contact metamorphism is usually a light-green, compact rock. In thin section, this rock is seen to be made up of calcite, augite, garnet, and, less abundantly, of zoisite and vesuvianite. The relative abundance of these minerals varies greatly in different specimens. In many places there occurs, as phenocrysts as much as 5 centimeters long, a dark augite with purplish tinge. Less abundant than this light-green, dense rock is a somewhat coarser dark rock which contains a larger percentage of yellow to brown garnets and deep-colored augite. Within the contact metamorphic rock are numerous pockets and nests of magnetite. These pockets of ore, though small, contain very little gangue. They are usually separated from the surrounding light-green rock by a narrow zone of the darker coarse-grained mixture of garnet and augite. A study of polished sections of this ore, one of which is reproduced in Plate II, *F*, showed that it consists of both ilmenite and magnetite; and, though seemingly not as abundant in amount as in the magmatic segregations, the ilmenite forms a considerable part of the ore. From a scientific standpoint, this is the most important and striking feature of the district—the occurrence of highly titaniferous iron ore of contact metamorphic origin.

REPLACEMENT ORES.

A third type of ore in the district is a replacement of the limestone, which, as it is not titaniferous, is of no particular interest in this connection, though the ultimate source of the iron was probably the same in all three types.

METALLOGRAPHIC DESCRIPTION OF THE ORE.

Though the individual segregations are small, the ore itself is rather high grade, and polished sections contain little gangue. The average percentage of gangue on a number of polished surfaces of the ore scarcely exceeds 15 per cent. The ore grains average from 2 to 5 mm. In some cases they reach as much as 10 mm. and few are smaller than 0.5 mm. The ratio of ilmenite to magnetite varies between wide limits in different specimens but is uniformly great, indicating an ore high in titanium. No analyses were made of this ore, but Chauvenet gives the range of TiO_2 between 9 and 36 per cent. In only a few sections did the magnetite exceed the ilmenite; and in some cases the ilmenite made up more than three-fourths of the surface. A very common relation of ilmenite to magnetite is that illustrated in Plate II, *E*. The two minerals, magnetite and ilmenite, are of so nearly the same hardness that no differences in relief are brought out by the ordinary amount of polishing. Two specimens (Pl. II, *E* and *F*) of this ore, however, which were polished longer than usual show a slight difference. The highly polished surface of the ilmenite has been cut back a little so that the magnetite stands out in slight relief.

The inclusions of ilmenite in the magnetite present several features of interest. One of the larger features is the segregation of irregular elongated particles of ilmenite about the periphery of ilmenite grains. These particles are not in direct contact with the ilmenite, but are separated from it by a narrow zone of magnetite free from ilmenite. This is well shown at the right end of Plate II, *E*. The effect is different from that described in the case of the Adirondack ore and illustrated in Plate VI, *B*. In this case the elongated particles of ilmenite are arranged parallel to the outline of the large grains, whereas in the case of the Adirondack ore they tend to orient themselves at right angles to them. Hence the broad, somewhat continuous bands formed by the coalescing of the ilmenite particles in the Adirondack ore are not found in the Colorado ore.

Many of the sections showed a tendency for the ilmenite to occur as a thin layer between the individual magnetite grains, so that their outlines are marked by a bright line of ilmenite, as has been illustrated in Plate IV, *A*. In places, instead of the simple film of ilmenite, there is a marked development of lamellæ along the outline as is seen in Plate XV, *B*. Very similar intergrowths were observed in some of the Iron Mountain, Wyo., ores, and are shown in Plate XIII, *B*.

A network of large intersecting lamellæ, as in Plate XV, *B*, is not very common, but is in places unusually well developed, the lamellæ attaining a length of 2 mm. In one section, characterized by an unusually heavy network, the thickness of the lamellæ was 0.07 mm. In most cases the network is poorly developed; the lamellæ occur in only a part of the magnetite crystals, only one series being prominent, or they are extremely short and faint. The short lamellæ are particularly well illustrated in a section of the contact metamorphic ore reproduced in Plate XVI, *A*.

The most common form of ilmenite inclusion is as minute dots. Many of the magnetite grains are swarming full of such minute particles of ilmenite. As a rule they seem to be distributed without any regularity, but in places they tend to have a linear arrangement. This may even become sufficiently pronounced to give the effect of a triangular network of dotted lines. In some cases the dots are slightly elongated, and the network made still more striking. It would seem therefore that the swarms of minute dots represent the incipient stage in the formation of the network of intersecting ilmenite lamellæ. The linear arrangement of the dots on the polished surfaces represents the orientation of the dots into planes parallel to the octahedral faces of the crystallizing magnetite. The elongation of the dots is caused by the coalescing of several dots. As this process continues small lamellæ of ilmenite are formed in intersecting series of parallel plates.

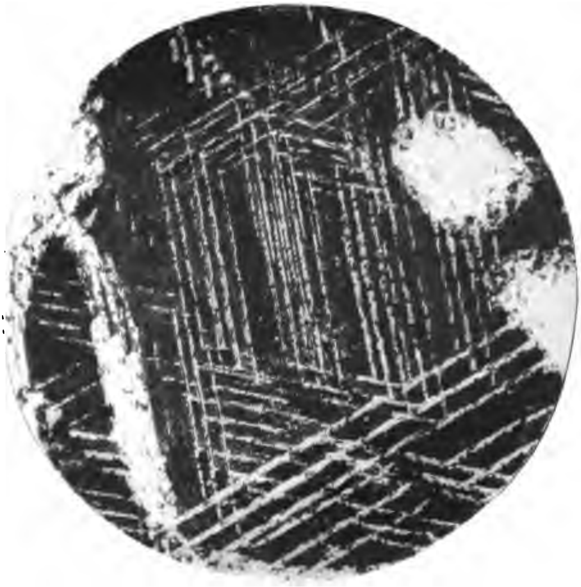
POSSIBILITIES OF UTILIZING ORE.

The possibilities of these ores are not very promising. Although a considerable tonnage of ore doubtless exists, it occurs in the form of countless small segregations, so that large-scale operations are impossible. Magnetic concentration to obtain a concentrate low in titanium is not feasible, because ilmenite forms more than 50 per cent of the ore, so that the percentage of magnetite concentrate obtained would be very small. The inaccessible location of the deposit is also a serious drawback.

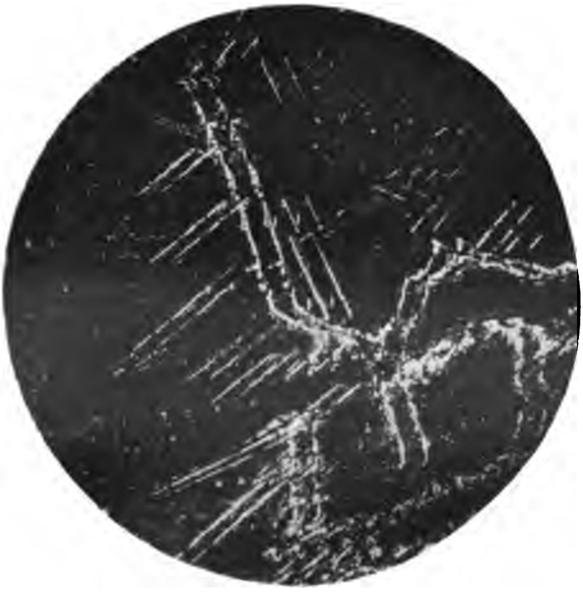
RÉSUMÉ.

The evolution of the modern blast furnace has taken place in such a direction as to make the utilization of titaniferous iron ores impracticable. Notwithstanding numerous experiments that have been conducted with a view to discovering a furnace charge that will make the use of these ores practicable from the standpoint of furnace operation and economy, there is to-day no hopeful feeling in regard to the possibilities of smelting these ores in the blast furnace. On the other hand, the introduction of the electric furnace holds out a new hope for the direct reduction of the titaniferous ores.

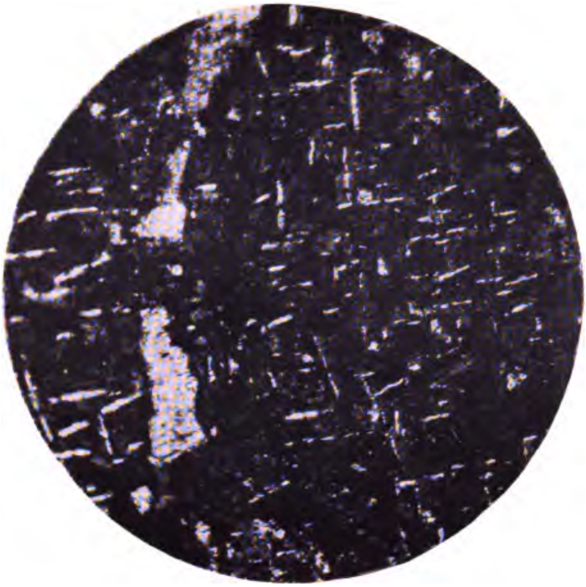
The results of magnetic-separation experiments conducted with these ores are very promising in some cases and extremely disap-



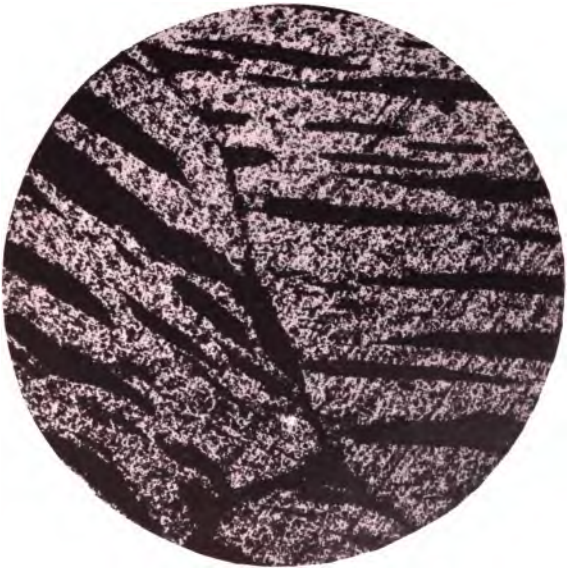
A. CEBOLLA CREEK, COLO., ORE. (X 60.)



B. CEBOLLA CREEK, COLO., ORE. (X 60.)



A. CEBOLLA CREEK, COLO., ORE. (× 60.)



B. RIVER CHALOUPE, CANADA, ORE. (× 60.)

pointing in others. No rule of general application can be formulated as to the behavior of the ores. Some deposits are very amenable to magnetic separation, and yield concentrates that require the admixture of only a small proportion of nontitaniferous ores to make a satisfactory ore mixture. Other deposits are less amenable and yield concentrates that would have to be mixed with three or four parts of nontitaniferous ores for furnace use. There are many other deposits in which the percentage of titanium separable in this way is extremely small, so that the utilization of such ores seems to depend on the discovery of a process that will make their use feasible.

The cause of the difference in behavior of the ores toward magnetic separation is revealed in their microstructure which is readily studied by the metallographic method. This method of investigation shows that the titanium occurs in these ores in the form of ilmenite grains in about the same order of magnitude as the magnetite grains, as ilmenite inclusions and intergrowths of microscopic size in the magnetite, and as an integral part of the magnetite molecule itself. The titanium occurring in the first form (as ilmenite grains) is readily separable by means of magnetic concentration, except in the finest grained ores with which the degree of crushing required would make such concentration impracticable. The titanium occurring in the two latter forms is inseparable by mechanical means. The percentages of tatanium occurring in these different forms varies greatly in the different ores, and, consequently, every case must be tested for itself. A metallographic study of the ores of any deposit will at once decide the question of the amenability of the deposit to magnetic separation.

As regards chemical composition, except for their titanium content, the ores are very desirable. The coarser-grained ores are usually high grade in their natural condition, whereas a magnetic separation of the leaner ores yields a high-grade concentrate, with the deleterious constituents at a minimum.

As the iron industry at present demands large deposits of definite extent, the outlook for most of the deposits of titaniferous iron ore in the United States is not promising. As a rule the deposits are relatively small and of irregular extent and distribution. Further, they are lean to medium grade, and inaccessibly situated as regards transportation facilities. In other words, to put the deposits on a producing basis would require a heavy initial outlay of capital, which the size and irregularity of occurrence does not warrant. There are, however, the two large, high-grade deposits of Sanford Hill, N. Y., and Iron Mountain, Wyo., which are so readily workable that, despite their titaniferous character, their utilization within a few years seems certain.

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